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UNDERWATER CONCRETE INSPECTION EQUIPMENT

ABSTRACT This report describes the development of three specialized instruments for the underwater nondestructive testing of concrete waterfront structures. One instrument is a magnetic rebar locator that locates rebar in concrete structures and measures the amount of concrete cover over the rebar. Another instrument is a rebound hammer that measures the surface hardness of the concrete. The third instrument is an ultrasonic test system that provides a general condition rating of the concrete based on sound velocity measurements. Each instrument consists of an underwater sensor connected to a topside deck unit via a buoyant umbilical cable. The battery-powered deck unit contains the signal conditioning electronics and data acquisition system. To operate each instrument, a diver must position the underwater sensor while a person topside operates the deck unit to collect and store data. Each independent instrument provides unique information to help assess the condition of the concrete structure.

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METRIC CONVERSION FACTORS

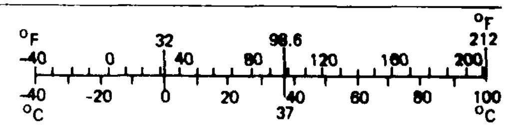
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10 286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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13. ABSTRACT *(Maximum 200 words)*

This report describes the development of three specialized instruments for the underwater nondestructive testing of concrete waterfront structures. One instrument is a magnetic rebar locator that locates rebar in concrete structures and measures the amount of concrete cover over the rebar. Another instrument is a rebound hammer that measures the surface hardness of the concrete. The third instrument is an ultrasonic test system that provides a general condition rating of the concrete based on sound velocity measurements. Each instrument consists of an underwater sensor connected to a topside deck unit via a buoyant umbilical cable. The battery-powered deck unit contains the signal conditioning electronics and data acquisition system. To operate each instrument, a diver must position the underwater sensor while a person topside operates the deck unit to collect and store data. Each independent instrument provides unique information to help assess the condition of the concrete structure.

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INTRODUCTION

Under the sponsorship of the Naval Facilities Engineering Command (NAVFAC), the Naval Civil Engineering Laboratory (NCEL) has developed three specialized instruments for the underwater inspection of concrete waterfront structures. These specialized instruments are: (1) a magnetic rebar locator, (2) a rebound hammer, and (3) an ultrasonic system. The magnetic rebar locator is used to locate rebar in concrete structures and measure the amount of concrete cover over the rebar. The rebound hammer is used to evaluate the surface hardness of the concrete and obtain a general condition assessment. The ultrasonic system is used to obtain a general condition rating of the concrete based on sound velocity measurements.

Each instrument consists of an underwater sensor connected to a topside deck unit through an umbilical cable. The deck unit contains the signal conditioning electronics and the data acquisition system. To operate the instruments, a diver has to position the underwater sensor and a person topside must operate the data acquisition system in order to collect and store the data. Each instrument is independently operated and provides unique information to help assess the condition of the concrete structure.

This report describes the development of the underwater concrete inspection equipment and documents the design of each instrument to support authorization for Navy use (ANU).

BACKGROUND

Currently, underwater inspections of concrete structures are conducted visually to assess the condition of the facility. The qualitative data obtained from visual inspections are sometimes inadequate to accurately assess the condition of the structure. Consequently, improved methods are needed to help detect and quantify deterioration in submerged concrete structures.

Many techniques for testing concrete above water have been developed and are generally well documented (Ref 1). In FY86, NCEL completed a project that assessed potential techniques for the nondestructive testing of concrete underwater (Ref 2). The project identified those techniques most easily adapted for inspecting concrete structures underwater. They are:

- Magnetic Rebar Location - Magnetic rebar location devices detect the distortion in a magnetic flux field caused by the presence of metallic rebar.

- Rebound Method - The compressive strength of the concrete is correlated with the rebound height of a spring driven mass after impact.

- Ultrasonic Testing - The transit time of high-frequency sound waves is used to assess the condition of the concrete and detect internal defects.

- Radiographic Tomography - The absorption and scatter of radiation is used to produce a visual image of the concrete cross section at the point of inspection indicating the thickness and density.

- Surface Hardness - The compressive strength of the concrete is correlated with the size of an indentation produced by a mass impacting the surface.

- Penetration Techniques - The compressive strength of concrete is correlated with the depth of penetration of a hardened probe.

- Pullout Testing Techniques - The compressive strength of concrete is correlated with the force required to pull out an anchor rod embedded in the surface of the concrete. This is a destructive test and not desirable for underwater inspections because of the probability of exposing rebar.

- Coring - Coring is the standard technique for determining the quality and strength of concrete. Underwater coring equipment has been developed and is available. Generally, coring should only be considered when other inspection techniques indicate a serious problem.

The first three techniques listed above offered the greatest potential to improve the Navy's ability to inspect concrete structures underwater. Consequently, three commercial instruments, one representing each technique, were obtained and modified for use underwater (Ref 2). Each experimental prototype was evaluated in laboratory and field tests to identify any fundamental problems with its operation underwater. The only problem encountered was a 23 percent shift in the output data from the rebound hammer which was caused by a design error. This shift was eliminated in a subsequent redesign effort. The modifications did not affect the data from the other two instruments and all of the instruments were easily operated by a diver.

Based upon the results of the above work, NCEL designed and fabricated an advanced development model (ADM) of each instrument for test and evaluation. Developmental test results for each ADM are described in this report. After completing the developmental and operational field tests and evaluations of the ADMs, NCEL implemented recommended design changes and fabricated the engineering development models (EDMs) of each instrument. In addition, a test and evaluation master plan (TEMP) was prepared to provide guidelines for this development (Ref 3), and an integrated logistic support plan was written (Ref 4) that covers the concrete inspection equipment.

Due to the specialized nature of the equipment, only two sets of each inspection system were fabricated for use by the Underwater Construction Teams (UCTs) and other government personnel. This equipment is stored and maintained at the Ocean Construction Equipment Inventory (OCEI) Support Facility at St. Julians Creek Annex, Portsmouth, Virginia, which is operated by the Chesapeake Division, Naval Facilities Engineering Command, Code FPO-1. Procurement plans do not include providing inspection systems for the UCTs Table of Allowances or contingency repair kits.

REBAR LOCATOR

Commercial System Description

Reinforcing bar location devices detect the disturbance in a magnetic flux field caused by the presence of magnetic material. The magnitude of this disturbance is used to determine the location and orientation of steel reinforcing bars in concrete and to measure the depth of concrete cover over the rebar.

Rebar locator devices typically consist of two coils mounted on a U-shaped magnetic core. A magnetic field is produced by applying an alternating current to one coil and measuring the current induced in the other coil. The magnitude of the induced current is affected by both the diameter of the rebar and its distance from the coils. Therefore, if either of the parameters is known, the other can be determined. By scanning with the probe until a peak reading is obtained, the location of the rebar can also be determined. A maximum deflection of the meter needle will occur when the axis of the probe poles are parallel to and directly over the axis of a reinforcing bar, thus indicating orientation.

A commercial rebar locator, called an R-Meter, Model C-4956, was purchased to be modified for underwater use (Figure 1). This instrument is powered by a rechargeable 12-volt, 4.5-ampere-hour storage battery and operates for about 16 hours between charges. To fully recharge the battery from a completely discharged state requires about 16 hours. A detailed operations manual is supplied with the unit (Ref 5).

The R-Meter is calibrated for rebar that varies from a No. 3 to a No. 16 in size. The R-Meter can be used to measure the depth of concrete cover over rebar in the range of 1/4 to 8 inches thick, or conversely, it can measure the diameter of the rebar. The amount of concrete cover measured with the R-Meter corresponds to the distance between the tips of the probe which are placed on the surface of the concrete and the top of the reinforcing bar located inside the concrete. The best accuracy (± 10 percent) is obtained for concrete cover less than 4 inches thick.

When using the R-Meter, the meter zero must be set accurately and rechecked frequently to obtain maximum accuracy for concrete cover measurements. The meter zero will drift with the battery charge level and temperature variations, which introduces an error into the measurement. This effect is more pronounced for increased concrete cover and smaller diameter rebar.

Engineering Development Model

The engineering development model of the underwater rebar locator system is shown in Figure 2. It consists of an underwater test probe, an umbilical cable, and a topside data acquisition unit (DAU) including printer. To modify the commercial R-Meter for underwater use, it was necessary to waterproof the test probe, provide a remote indicator to orient the diver while using the probe, and interconnect the probe through an umbilical cable to the DAU. The DAU contains the signal conditioning electronics and data acquisition system. Table 1 lists the system specifications for the rebar locator.

Underwater Test Probe. The underwater test probe is shown in Figure 3 and the mechanical design drawing can be found in Appendix A. The underwater test probe consists of a small pressure housing attached to the original R-Meter test probe. The original probe was

waterproofed by epoxying a thin delrin wear pad over the exposed metal tips of the probe. The pressure housing contains the diver readout, a pressure transducer, a diver earphone connector, and the umbilical cable connector. The diver readout is a small voltmeter (0 to 5 VDC) that duplicates the analog meter movement from the topside deck unit. The diver uses this readout to locate rebar and orient the probe to measure the depth of concrete cover. The pressure transducer is used to automatically measure water depth each time a measurement is taken by the DAU. A diver earphone can be connected to the test probe to form a one-way communications link from the topside operator down to the diver. This link is used to help coordinate taking the underwater measurements. A metal shell underwater connector is used to terminate the umbilical cable.

Umbilical Cable. The umbilical cable is 200 feet long and is stored on a portable cable reel placed inside a shipping container (Figure 4). The mechanical/electrical design drawings for the umbilical cable are in Appendix B. The cable is designed to be slightly buoyant so the diver can more easily maneuver the cable during an underwater inspection. Positive buoyancy is obtained by running a standard electrical cable containing nine twisted, shielded pairs of 20-gauge wire and a RG-174 coaxial cable inside a polyurethane tube. An expandable braided polyester sleeve was placed over the polyurethane tube for added protection and increased abrasion resistance. A rugged metal shell underwater connector terminates each end of the umbilical cable. The design of the umbilical cable is identical for each of the three concrete inspection instruments.

Data Acquisition Unit (DAU). The DAU for the rebar locator is shown in Figure 5. It contains a microprocessor-based data acquisition system, signal conditioning electronics from the commercial R-Meter, and a self-contained battery pack with a built-in battery charging system. It supplies power to, and receives signals from, the underwater test probe via the umbilical cable. Data received from the probe are displayed on a digital display and analog meter. The DAU is powered by a rechargeable 12-volt, 8-ampere-hour battery pack that operates the system for a minimum of 8 hours between battery charges. The DAU controls, indicators, and operating menus are fully described in the rebar locator technical manual (Ref 6). A detailed block diagram of the rebar locator is shown in Figure 6 and the electrical schematic for the system is given in Appendix C.

The signal conditioning circuits for the rebar locator are represented in the block diagram (Figure 6) as the R-Meter electronics module. This module produces an analog voltage level inversely proportional to the distance between a metal object and the probe. The analog output signal from the module is provided to the computer via the analog-to-digital (A/D) converter. When the rebar size is entered through the keypad, the computer can calculate the depth of concrete covering the rebar from the known depth-voltage characteristic. The remaining input to the A/D converter module is the output of the pressure transducer mounted in the underwater test probe. The microprocessor uses readings from this to calculate the diver's depth.

The analog output voltage also drives a calibrated analog display from the original R-Meter mounted in the lid of the DAU, and two uncalibrated meters. One uncalibrated meter is located in the underwater test probe and the other meter is mounted beside the calibrated meter in the DAU to indicate what the diver is actually seeing. The sensitivity of the uncalibrated meters can be adjusted to one of two levels by the position of a X1 or X2 gain switch located on the top panel of the DAU.

The DAU contains a data acquisition system based on the MA2000 family of low power microcomponents from National Semiconductor, which consists of several small modules physically plugged together in a stacked arrangement. The microprocessor is an NSC800 contained within the MA2800 CPU module. It provides the computation and input/output (I/O) functions required by the system. The system program is contained in two 4K EPROMS mounted on the MA2732 UVPROM/RAM module. The A/D converter is contained in the MA2400 module and it has a 12-bit resolution with internal variable gain amplifier. The data storage requirement is handled by one MA2018 Static RAM Module, providing 16K bytes of memory. Serial data transmission to the printer is done by using the MA2232 I/O Module which provides an RS232 interface between the microprocessor and the printer. DC power to the microcomputer system is supplied by the MA2000 Power Supply Module, which in turn is supplied by the battery pack or from the internal power supply via a voltage regulator circuit. The system has the feature of retaining stored data after power is turned off, due to a battery contained in the MA2000 module which supplies the memory with voltage when the main system is turned off.

Commands to the computer system are entered from a keypad consisting of 16 keys. An encoder circuit produces a binary input to the microcomputer parallel port corresponding to the key pressed, and also an interrupt to the interrupt controller signaling to the microcomputer that the key code is ready to be read. Multiple functions for the keys, including the ability to utilize the full alphabet and all 10 decimal digits, is possible by using a software keypad reading routine. Display information for interacting with the computer is provided by a 4-line by 40-character liquid crystal display. Data to the display are transmitted serially from the computer to minimize the number of parallel I/O lines required of the computer. Translation of the data stream to parallel form required by the 4X40 liquid crystal display (LCD) is done by use of a serial-to-parallel integrated circuit.

A one-way communication channel to the diver is provided by an intercom circuit. A handheld microphone, push-button activated, can be plugged into a jack on the top panel of the DAU. A volume adjust knob next to the jack can be used to control the volume of the voice communications heard by the diver through a waterproof earphone, which is plugged into a connector on the underwater test probe.

To protect the lead-acid batteries against over-discharge, a battery latch-out circuit is provided. The battery latch-out circuit activates to isolate the batteries from the system circuits when either the power switch is turned off or when a minimum safe battery operating voltage is sensed. To turn the system on, the power switch is first switched to the ON position and then the PUSH ON switch is depressed. Successful turn-on is signaled by the POWER ON light emitting diode (LED).

In addition to the above two steps, two more steps are required to charge the battery pack. The power cord must connect the DAU to a 120-VAC outlet and the ventilation door on the right side of the DAU must be open. When the system is turned on to charge the batteries, both the POWER ON LED and the CHARGER ON LED will glow and the ventilation fan will be operating.

The battery charging circuit uses a charging integrated circuit (IC) specifically designed for lead-acid batteries. Using temperature compensation tailored to the characteristics of lead-acid batteries and controlled charge cycle stages initiated by sensing the state of the battery pack charge state, the charger optimizes the capacity and useful life of the battery pack. Using a few additional components, the charging IC is configured as a "dual level float charger," providing the battery

pack with three states during the charge cycle. A constant current bulk charge first returns 70 to 90 percent of battery capacity and the remaining capacity is returned during an elevated, constant voltage overcharge. A float-charge state follows, which maintains a precise voltage across the battery pack. The float-charge condition is sensed and used to activate a "fully-charged" indicator lamp on the top panel of the DAU.

Data Output. The DAU stores all data measured or entered into the system during an inspection. The data are stored in battery-protected memory, making the data available for retrieval at a later date. Power can be interrupted to the DAU and the data will remain in memory. After completion of an inspection, the test results can be transmitted to a printer in report form. A printout (Figure 7) of data stored in the DAU contains the following general information: activity name, facility name, property record number, and date. This information is entered by the operator using the DAU keypad and describes where and when the work was performed. Most of the output report consists of the following information either entered directly by the operator or measured by the system:

1. Location - This information is entered by the operator and describes the position where the measurement was made.

2. Depth - This information is measured and logged by the system each time a measurement is made. The output is rounded to the nearest foot.

3. Rebar Size - This information is entered by the operator and is required to accurately calculate the amount of concrete cover. A rebar size chart is listed in Table 2.

4. Concrete Cover - This information is measured and logged by the system each time a measurement is made. The output estimates the depth of concrete covering the rebar.

System Limitations. The primary limitation that affects the operation of the rebar locator is the presence of other metallic objects in the vicinity of the rebar where the measurement is being made. For example, in heavily reinforced structures, the effect of nearby rebar cannot be eliminated and accurate depth readings are difficult or impossible. The effects of parallel 1-inch-diameter rebar, located 2 inches below the surface of the concrete, are shown in Figure 8 taken from Reference 5. Theoretically, if the separation of the axes of two parallel rebars is at least three times the thickness of the concrete cover, this effect can be neglected. In routine measurements, if the R-Meter display needle drops to a value of one or less on the linear scale when the underwater probe is between the two bars, the effect can be neglected.

The presence of rebar perpendicular to the axis of the underwater probe has less effect on the measurement of concrete cover than that of parallel rebar, and in most instances it can be ignored. For example, if the perpendicular rebar is located beneath the rebar under test, the effect is negligible.

REBOUND HAMMER

Commercial System Description

A commercial rebound hammer, called the H-Meter, Model C-7311, was purchased to be modified for underwater use and is shown in Figure 9. A calibration anvil, Model C-7312, was obtained for checking the calibration of the hammer and a detailed operations manual was supplied with the H-Meter (Ref 7).

The H-Meter utilizes the rebound method for determining the compressive strength of concrete. This is accomplished by correlating the rebound height of a spring-driven mass, after it impacts the surface of the concrete, with the compressive strength of the concrete under test. The impact energy is 1.63 foot-pounds. A cutaway view of the hammer, illustrating the internal mechanisms, is shown in Figure 10.

The H-Meter is principally a surface hardness tester. It consists of a spring-driven mass that slides on a guide rod within the tubular housing as shown in Figure 10. To carry out a test, the impact plunger is pressed firmly against the concrete surface under test. This releases the spring-loaded mass from its locked position causing it to impact the plunger which transfers the energy to the concrete surface. The mass then rebounds, taking the reading pointer with it along the guide rod. By pushing a button, the operator can hold the pointer in position while the graduated plate is read to the nearest whole number. This value is referred to as the rebound number and can vary over the range of 10 to 100 with higher numbers indicating stronger concrete. It is recommended that a minimum of twelve readings be taken per test site and averaged after disgarding the minimum and maximum values (Ref 7). A general calibration chart that relates the rebound number to cube compressive strength for the Model C-7311 H-Meter, taken from Reference 7, is shown in Figure 11.

Engineering Development Model

The engineering development model of the underwater rebound hammer system is shown in Figure 12. The system consists of an underwater rebound hammer, an umbilical cable, and a topside data acquisition unit (DAU) including printer. To use the H-Meter underwater, it was necessary to place the hammer in a waterproof housing, add an electrical pickup to sense the position of the rebound pointer, and interconnect the hammer through an umbilical cable to the DAU. The DAU contains most of the signal conditioning electronics and data acquisition system. Table 3 lists the system specifications for the rebound hammer system.

Underwater Rebound Hammer. The underwater rebound hammer is shown in Figure 13 and the mechanical design drawings can be found in Appendix D. To use the commercial rebound hammer underwater, it was necessary to place the hammer inside a pressure compensated aluminum housing with a double O-ring seal on the impact plunger shaft. Pressure compensation was required for correct underwater operation of the rebound hammer and to maintain a reliable shaft seal. All internal parts of the hammer remained unchanged except for the mechanical reading pointer and the impact plunger. The reading pointer was replaced with a resistive film to

electronically detect the maximum rebound height of the hammer mass. The impact plunger was lengthened about 1/2 inch to accommodate the shaft seal. The mass and hardness of the new plunger matched the original impact plunger in order to maintain hammer calibration.

The pressure housing has a depth rating of 190 feet and it is pressure compensated at 5 psi over the ambient pressure. Air is supplied to the rebound hammer through the umbilical cable via an external pressure regulator to maintain the positive pressure differential inside the housing. The external pressure regulator, shown in Figure 13, is adjusted to set the internal pressure at 4 to 6 psi. The regulator then maintains this pressure differential as the ambient pressure changes with water depth. A relief valve set at 5 psi is located inside the underwater rebound hammer to prevent overpressuring the metal housing.

A standard dive tank is used topside for suppling air to the umbilical cable to pressure compensate the underwater rebound hammer, as shown in Figure 14. The pressure regulator, attached to the dive tank, maintains the pressure inside the cable at 50 psi or less. Detailed setup procedures are fully described in the rebound hammer technical manual (Ref 8).

The pressure housing also contains a pressure transducer, diver status light, diver earphone connector, and the umbilical cable connector. The pressure transducer was included for measuring water depth to provide location information feedback. A status light was added for visual feedback to the diver. A diver earphone can be plugged into the back of the hammer for using the audio link from the surface to help coordinate the inspection. A modified metal shell underwater connector was used to terminate the umbilical cable. The modified connector will pass air from the umbilical cable into the hammer via the external pressure regulator. A forearm rest with velcro strap and a handle grip were provided to help the diver operate the underwater rebound hammer.

Umbilical Cable. The umbilical cable for the rebound hammer is the same cable used for the rebar locator shown in Figure 4. However, when the cable is used with the rebound hammer it is pressurized with air to 50 psi or less in order to pressure compensate the hammer.

Data Acquisition Unit (DAU). The DAU (Figure 15) for the underwater rebound hammer system is very similar in appearance and operation to the DAU used with the underwater rebar locator. It contains a microprocessor-based data acquisition system, signal conditioning electronics, and a self-contained battery pack with a built-in battery charging system. It supplies power to and receives signals from the underwater rebound hammer via the umbilical cable. Data received from the hammer are shown on a digital display. The DAU is powered by a rechargeable 18-VDC, 8-ampere-hour battery pack that operates the system for a minimum of 8 hours between battery charges. The DAU controls, indicators, and operating menus are fully described in the rebound hammer technical manual (Ref 8). A detailed block diagram of the rebound hammer system is shown in Figure 16 and the detailed electrical schematic for the system is given in Appendix E.

The DAU contains the same data acquisition system, communications channel, battery protection, and charging circuits described for the rebar locator in the previous section. The only difference in hardware is the signal conditioning circuits.

The output of the position to voltage transducer (resistive film) located in the underwater pressure housing goes to a peak catcher circuit in the DAU as shown in Figure 16. The peak catcher circuit captures the peak output signal from the resistive film corresponding to the

maximum rebound height of the hammer mass. The peak catcher circuit then interrupts the microcomputer and sends a voltage proportional to the maximum rebound height to the A/D converter module for processing. The input angle, which is keyed in by the DAU operator, and the rebound value are used by the computer to calculate the compressive strength of the concrete under test based on the calibration chart shown in Figure 11.

A diver status light turns on when the underwater rebound hammer is ready for collecting data and turns off when the preset number of measurements have been made. The diver must take between 3 and 18 measurements at each test location. The number of samples to be taken is selected by the DAU operator. A minimum of 12 samples are recommended per test location. The multiple number of samples allows the computer to calculate the mean value and standard deviation of the measurements after discarding the minimum and maximum values.

Calibration. Calibration of the underwater rebound hammer should be periodically checked using the calibration anvil provided with the system. The anvil is made of hardened steel and forms a surface where a reference reading can be obtained for checking calibration. The optimum rebound value from a calibration check is 80 with a standard deviation of 2 or less. Internal adjustments can be made in the rebound hammer to make small variations in the output to match the anvil reference reading, but this adjustment cannot be made in the field. However, the calibration rebound value can vary over the range of 70 to 85 and the data are still valid if normalized. Consequently, all measurements taken with the rebound hammer are normalized against the last calibration rebound value using the following expression:

$$R = \frac{r \times 80}{n \times Ra}$$

where R = Normalized rebound number
r = Measured rebound numbers
n = Number of measurements
Ra = Calibration rebound value

The normalized rebound number is used to estimate compressive strength based on the general calibration chart shown in Figure 11.

Data Output. The DAU stores all data measured or entered into the system during an inspection. The data are stored in battery-protected memory, making the data available for retrieval at a later date. Power can be interrupted to the DAU and the data will remain in memory. After completion of an inspection, the test results can be transmitted to a printer in report form. A printout (Figure 17) of data stored in the DAU contains the following general information: activity name, facility name, property record number, and date. This information is entered by the operator using the DAU keypad and describes where and when the work was performed. Most of the output report consists of the following information either entered directly by the operator or measured by the system:

1. Location - This information is entered by the operator and describes the position where the measurement was made or indicates data measured during a calibration check.

2. Depth - This information is measured and logged by the system each time a measurement is made except during a calibration check. The output is rounded to the nearest foot.

3. Rebound - This value is the average of the rebound numbers measured by the system after dropping the high and low data points. The range of this number is 10 to 100 with higher numbers indicating stronger concrete. The rebound value from a calibration check must fall within the range of 70 to 85.

4. Std Dev - This value is the standard deviation of the rebound number data with smaller numbers indicating more consistent data. The standard deviation should be 2 or less for a good calibration check.

5. Rebound Corrected - This value is the rebound number corrected for changes in system calibration based on the value measured during the last calibration check.

6. Est Stren - This value is the estimated compressive strength of the concrete under test based upon a calibration curve that relates the corrected rebound number to the compressive strength of a "standard" concrete cube "consisting of good quality aggregate and Portland cement." The calibration curve was provided with the Model C-7311 H-Meter which was used in the underwater rebound hammer. The curve compensates for the orientation of the hammer when making a measurement.

7. Samples - This information is entered by the DAU operator and sets the number of data samples to be collected at that particular location. This value can range from 3 to 18 samples with 12 being the recommended minimum data set for a given test location.

System Limitations. The underwater rebound hammer has several limitations that should be recognized when using this instrument to obtain surface hardness data. For example, the test results obtained with the hammer are affected by the following things:

1. Smoothness of the concrete surface under test has an important effect on the accuracy of the test results. Higher rebound numbers are generally obtained from smoother surfaces and the scatter in the data tends to be less. Minimizing the data scatter increases the confidence in the test results. Therefore, underwater concrete surfaces must be thoroughly cleaned and smoothed with something like a corborundum stone before measurements are taken.

2. Surface and internal moisture condition of the concrete also affects the results. Saturated concrete tends to show rebound readings 5 points lower than when tested dry. This affects the comparison of data taken above and below the waterline.

3. Type of coarse aggregate and cement seriously affects the correlation of the rebound numbers with actual compressive strength of the concrete under test. A calibration curve is required for each particular concrete mix to assure accuracy. This is not practical for most situations, therefore, the data should only be used for making comparative measurements from one location to another within a uniform concrete structure.

4. Size, shape, rigidity, and age of the concrete become important when testing small concrete samples or recently poured concrete. This should not be a concern for the underwater inspection application.

Because of these limitations, which are discussed more fully in Reference 2, the estimation of concrete compressive strength obtained with a rebound hammer is only accurate to about ±25 percent. This applies to concrete specimens cast, cured, and tested under the identical conditions as those from which the calibration curves were established. Because of the lack of accurate calibration data correlating average bulk compressive strength with rebound numbers, the rebound hammer is primarily useful for checking surface compressive strength or surface hardness and uniformity of concrete. It can also be used to compare one concrete structure against another if they are assumed to be reasonably similar.

ULTRASONIC SYSTEM

Commercial System Description

The transit time of high-frequency sound waves through concrete can be used to assess its condition. Ultrasonic testing procedures for concrete have been standardized by ASTM Standard C-597 (Ref 9) and test equipment is available from commercial sources for in-air testing. Measuring sound velocity in nonhomogeneous materials, such as concrete, requires using a separate transmit and receive transducer to avoid energy scattering problems. Sound velocity is calculated by measuring the time required to transmit over a known path length. The measurement of average sound velocity through concrete is recommended as a means to establish the uniformity of the concrete being tested (Ref 2). It is not recommended that average sound velocity be correlated with concrete compressive strength but rather used only as an indicator of concrete quality. Table 4 presents some suggested condition ratings for concrete based on sound velocity measurements (Ref 2).

There are three approaches to measuring sound velocity in concrete (Figure 18). The most common method is direct transmission where the transducers are positioned on opposite sides of the test specimen and the longitudinal waves propagate directly toward the receiver. For indirect transmission, both transducers are placed on the same side of the concrete and energy scattered by discontinuities within the concrete is detected by the receive transducer. The strength of the pulse detected in this case is generally less than 5 percent of the strength detected for the same path length when direct transmission is used. Semidirect transmission is not normally used because it is difficult to maintain a consistent or known path length.

Direct transmission of the ultrasonic pulse is the preferred approach for measuring the average sound velocity in concrete because this method provides maximum sensitivity with a well-defined path length. Indirect (surface) transmission is used only when one surface of the concrete is accessible, such as a concrete retaining wall. This approach does not have a well-defined path length and primarily indicates the quality of the concrete near the surface.

The commercial ultrasonic equipment used in the underwater ultrasonic system was the Model C-4901 V-Meter manufactured by James Electronics, Inc., and is shown in Figure 19. This instrument is representative of commercially available ultrasonic devices used for laboratory and

field testing of concrete. It generates low-frequency ultrasonic pulses and measures the time taken for them to pass from one transducer to the other through the material placed between them. The V-Meter displays the transit time directly on a digital readout. The overall time measurement range is 0.1 to 9999 microseconds, in three selectable intervals, with a resolution of 0.1, 1.0, and 10.0 microseconds depending on the selected interval. The accuracy of the time measurement is ±0.1 microseconds. The instrument can be operated from commercial power or a self-contained battery pack that provides 9 hours of continuous use. The V-Meter comes with a pair of lead zirconate titanite (PZT-4) piezolectric transducers, operating at a frequency of 54 kHz. The piezoelectric elements are mounted in rugged stainless steel housings. A metal calibration bar with a known sound pulse transit time is provided for calibrating the instrument. A detailed description of the Model C-4901 V-Meter and its operation can be found in Reference 10.

Engineering Development Model

The engineering development model of the underwater ultrasonic system is shown in Figure 20. The system consists of two different underwater transducer holders for direct and indirect sound velocity measurements. An umbilical cable connects either the direct or indirect transducer holder to the topside data acquisition unit (DAU). The DAU contains most of the signal conditioning electronics and data acquisition system. Table 5 lists the system specifications for the underwater ultrasonic system and the mechanical design drawings can be found in Appendix F.

Transducer Holders. There are two types of transducer holders included with the ultrasonic system. The direct transducer holder (Figure 21) is used to examine structures with accessible opposing surfaces; for example, concrete piles. The indirect transducer holder (Figure 22) is used to examine structures with only one accessible surface; for example, concrete bulkheads.

The direct transducer holder consists of a mechanical framework, transmit transducer, receive transducer, and a waterproof pressure housing that contains a digital display and other electronic components. A 54-kHz transducer is used for sound transmission and the receive transducer utilizes an exponential horn because of its small tip which helps to reduce surface coupling problems. Coaxial cables connect both transducers to the pressure housing via underwater coaxial connectors. A linear displacement transducer, located inside the transducer holder frame, accurately measures the distance between the transmit and receive transducers. These data are used to precisely calculate sound velocity. The framework can be adjusted to accommodate concrete pile sections that range from 8 inches to 24 inches thick. The digital display of sound wave transit time provides feedback to help the diver position the transducer holder for optimum results. The display is set to 00 after each measurement to let the diver know the data were logged by the computer.

A pressure transducer is also located inside the pressure housing for measuring water depth. A diver earphone can be plugged into an underwater connector on the pressure housing to use the audio link from the surface to help coordinate an inspection. The pulser and preamp circuits, in addition to the signal conditioning electronics for the displacement transducer, are also located in the pressure housings. A metal shell underwater connector is used to terminate the umbilical cable.

The indirect transducer holder is very similar to the direct transducer holder in operation except for the path length measurement which is fixed at 12 inches. The indirect holder consists of a different mechanical framework with suction cup and pump; the same transmit and receive transducers; and a pressure housing that contains the same digital display and electronic components as the direct transducer holder. However, a linear displacement transducer is not required due to the fixed path length. Both types of transducer holders interface to the same DAU, which automatically selects the type of operation (i.e., direct or indirect).

The suction cup was added to the indirect holder to force the transmit transducer firmly against the concrete surface under test and provide a reaction force for the diver. A small suction pump is used to pump water from the cup to provide a holding force of about 25 pounds depending on the surface condition of the concrete. The suction pump is turned on automatically by the DAU and operates off a 12-volt, 2.6-ampere-hour battery. The diver manually controls the suction force by regulating the flow of water through the suction cup.

Umbilical Cable. The umbilical cable for the underwater ultrasonic system is the same cable used for the rebar locator (Figure 4). Likewise, the cable is not pressurized when used with the ultrasonic system.

Data Acquisition Unit (DAU). The DAU (Figure 23) for the underwater ultrasonic system is very similar in appearance and operation to the DAUs used with the rebar locator and rebound hammer described previously. It contains a microprocessor-based data acquisition system, signal conditioning electronics, and a self-contained battery pack with a built-in battery charging system. It supplies power to and receives signals from the underwater transducer holders via the umbilical cable. Data received from the ultrasonic system are shown on two digital displays. The DAU is powered by a rechargeable 18-VDC, 8-ampere-hour battery pack that operates the system for a minimum of 8 hours between battery charges. The suction pump operates from its own dedicated 12-volt battery. The DAU controls, indicators, and operating menus are fully described in the ultrasonic system technical manual (Ref 11). Two block diagrams of the ultrasonic system for direct and indirect transmission are shown in Figures 24 and 25. Detailed electrical schematics for both the direct and indirect transmission systems are given in Appendixes G and H.

The DAU contains the same data acquisition system, communications channel, battery protection, and charging circuits previously described for the rebar locator. However, this DAU does contain an extra 12-volt battery for powering the suction pump on the indirect transducer holder. This battery is charged from the main battery pack, as required, during operation.

The receive transducer requires a preamplifier to drive the long return line. In addition, a blanking circuit is used to disable the receive signal input when the transmitter circuit excites the transducer to prevent false triggering of the V-Meter electronics. False triggering occurs when the transmit pulse is coupled into the sensitive receiver circuits.

The V-Meter electronics module contains the electronics for computing the transit time of the ultrasonic wave. The transit time from the V-Meter electronics is displayed on a four-digit display in the DAU. Also, the microcomputer inputs the transit time from a binary coded decimal output on the V-Meter module through a parallel-to-serial converter. The transit time is then sent serially to the diver display by the computer.

The output from the separation transducer in the direct transducer holder is sent to the A/D converter module for input into the computer. The separation distance and transit time are used by the computer to calculate sound velocity through the material. For the indirect holder, the distance is fixed at 12 inches. The other input to the A/D converter is the output from the pressure transducer used by the computer to calculate water depth.

Calibration. Calibration of the underwater ultrasonic system should be periodically checked using the calibration standard provided with the system. Detailed calibration procedures for the ultrasonic system are given in Reference 11. The SET REF control on the front panel of the DAU is used to adjust the system to agree with the calibration standard. The DAU automatically substracts 11 microseconds from the transit time measurements when data are processed to compensate for delay introduced by the transducers. The correct transit time calibration value logged by the computer is 51 (±1) microseconds.

Data Output. The DAU stores all data measured or entered into the system during an inspection. The data are stored in battery-protected memory, making the data available for retrieval at a later date. Power can be interrupted to the DAU and the data will remain in memory. After completion of an inspection, the test results can be transmitted to a printer in report form. A printout (Figure 26) of data stored in the DAU contains the following general information: activity name, facility name, property record number, and date. This information is entered by the operator using the DAU keypad and describes where and when the work was performed. Most of the output report consists of the following information either entered directly by the operator or measured by the system:

1. Location - This information is entered by the operator and describes the position where the measurement was made or indicates data measured during a calibration check.

2. Depth - This information is measured and logged by the system each time a measurement is made. The output is rounded to the nearest foot.

3. Time - This is the measured transit time, in microseconds, of the sound velocity pulse through the concrete under test. This value has been corrected for the time delay introduced by the transducers themselves.

4. Length - This value is the measured length of the sound velocity path rounded to the nearest inch. For indirect measurements this value is always 12.

5. Sound Vel - This value is the sound velocity in feet per second through the concrete calculated by dividing the path length by the transit time. The precision of the measured path length used in the calculation is better than 0.5 percent.

6. Concrete Rating - This value is an estimated general condition rating based on the measured sound velocity. The relationship between the general condition rating for concrete and the measured sound velocity is given in Table 4. This table is based on information presented in Reference 2.

7. Type - This value indicates the type of transducer holder used for the measurement. The type of transducer holder determines whether the measurement was made using direct or indirect transmission. Direct transmission is indicated by a "D" in this column, indirect transmission by an "I." The DAU automatically determines which holder is being used and records this information.

System Limitations. The ultrasonic system has several limitations that should be recognized when using this instrument to access the condition of concrete structures. For example, test results obtained with the ultrasonic test system are affected by the following factors which influence the quality of the data:

1. Concrete Surface Finish - The smoothness of the surface under test is important for maintaining good acoustical contact between the face of the transmit transducer and the surface of the concrete. Good acoustic coupling is necessary in order to make accurate and repeatable sound velocity measurements. The surface must be reasonably smooth and a coupling agent, such as silicone grease, must be placed between the transmit transducer and the concrete surface to transfer maximum energy. If a coupling agent is not used, the transmitted signal will be severely attenuated which results in large errors in the measurement of the transit time.

2. Signal Detection Threshold - The signal detection threshold of the ultrasonic system can cause erroneous transit time data to be recorded. This happens when the amplitude of the first peak of the received signal is below the threshold triggering level of the system. When the instrument detects a following peak, this causes an apparent transit time increase of one-half wavelength or more. This error is inversely proportional to the path length and the ultrasonic test frequency.

Reinforcing Steel. Sound velocity measurements taken near steel reinforcing bars may be high because the sound velocity in steel is 1.2 to 1.9 times the velocity in concrete. When the axis of the rebar is perpendicular to the direction of sound propagation, the effect is generally small and the correction factors are on the order of 1 to 4 percent depending on the quality of the concrete. If the axes of the rebar are parallel to the direction of sound propagation, reliable corrections are difficult to make and it is recommended that sound transmission paths be chosen that avoid the influence of the rebar.

Because of these limitations, it is recommended that the underwater ultrasonic system be used primarily for checking the uniformity of concrete from one test location to another in a given structure. If the data consistently indicate poor or very poor quality concrete, core samples must be taken and standard compression tests performed to confirm the results. Sound velocity measurements should not be considered as substitutes for standard compression tests.

EQUIPMENT SAFETY ASSESSMENT

Electrical Systems

The underwater concrete inspection equipment conforms to the electrical safety standards (Ref 12) adopted by Naval Sea Systems Command (NAVSEA) for protecting Navy divers from electrical shock while underwater. Each system is powered by an internal battery pack during underwater operations which does not constitute an electrical hazard to the diver. The maximum output voltage from each battery pack is 18 volts DC for the rebound hammer and ultrasonic system, but only 12 volts DC for the rebar locator. These voltage levels are below the nominal voltage level of 24 volts DC and well below the maximum level of 30 volts DC specified for systems without a trip device given in the electrical safety standards for handheld equipment and umbilical cables.

Prominent warnings are given in each technical manual specifing not to connect the equipment to a 120-VAC power source during underwater operations. If it is desired to operate the equipment from a 120-VAC power source during diver operations, a ground fault detector must be used which has been authorized for Navy use. A 1-amp fuse provides short circuit protection for the AC power source during normal topside operations such as battery recharging.

The battery pack in each system is located inside the DAU and it is properly secured to withstand rugged handling and shipping. A 1-amp fuse provides short circuit protection for each battery pack. A precision battery charging circuit has been included in each system to control the charging rate and to prevent overcharging the batteries. This controls outgassing from the batteries during charging and extends the life of the battery pack. An interlock circuit is included to prevent charging the batteries without properly venting the battery compartment, which prevents any heat build-up inside the DAU that might damage the integrated circuits.

Mechanical Systems

The concrete inspection equipment does not present a mechanical safety hazard to the diver during underwater operations. The rebar locator has no moving parts and does not generate any noise. The ultrasonic system has very limited motion which is controlled by the diver, and it generates a very low level clicking sound that indicates the transmit transducer is being energized. The diver uses this sound as an indicator the system is functioning. The rebound hammer also has very limited motion which is controlled by the diver and it generates a low level sound each time the hammer mass impacts the plunger. This sound is used by the diver to help operate the system.

Since the rebound hammer is actively pressure compensated during operation, a pressure relief valve set at 6 psi above ambient pressure is located inside the hammer to prevent overpressurizing the housing. The housing was pressure tested to a maximum internal pressure level of 100 psi above ambient pressure without failure in laboratory tests. The polyurethane tube in the umbilical cable acts as a backup to the pressure relief valve because it is only rated for operation at pressures up to 75 psi. However, the maximum pressure to be applied to the umbilical cable during operation is specified as 50 psi or less in the rebound hammer technical manual (Ref 8).

In summary, the concrete inspection equipment does not present an electrical or mechanical safety hazard to the diver during underwater operations.

ADM DEVELOPMENTAL TEST RESULTS

Objectives

The objectives of the developmental tests were to: (1) validate system performance thresholds as specified in the Test and Evaluation Master Plan (TEMP), Reference 3, (2) demonstrate system reliability, and (3) evaluate any human factor problems that could arise during operation. Laboratory tests were performed to collect data on the physical characteristics, accuracy, depth capability, environmental limits, and reliability of each instrument as specified in the test plan (Ref 13). Field tests were also performed to evaluate operational thresholds established in the TEMP and to perform human factors testing. A detailed report documenting the developmental tests on the concrete inspection equipment was prepared (Ref 14). The report includes the detailed test information and test data sheets to support the test results given for each of the three concrete inspection instruments.

Summary of Test Results

A summary of the developmental test results for the underwater (U/W) concrete inspection equipment is presented in the Tables 6 through 8. The tests performed on each instrument and the results are shown in each table along with the TEMP threshold value for comparison. A detailed discussion of the test results is provided in the developmental test report (Ref 14).

The objectives of the developmental tests performed on the U/W concrete inspection equipment were successfully met. All major system performance thresholds specified in the TEMP were validated for each of the three instruments except for the low temperature operating threshold. None of the instruments were able to operate at an ambient air temperature of 10 °F as specified in the TEMP due to component failures in the data acquisition units, however, operation down to 20 °F was demonstrated for each instrument. Therefore, we recommended revising the TEMP threshold to 28 °F as the most acceptable course of action because there would be no impact on development cost or schedule and only minimal impact on the practical operational capability of the equipment. The sponsor concurred with this recommendation.

Some physical characteristics of each instrument exceeded the thresholds established in the TEMP. Our initial field tests did not detect any major problems in handling or operating the instruments as they were designed. Therefore, no attempt was made to match TEMP thresholds before conducting user tests. All further design changes were based on user recommendations.

A reliability of 0.9 was demonstrated for the ultrasonic system and the rebar locator. A reliability of 0.88 was demonstrated for the rebound hammer which was very close to the TEMP threshold of 0.9 and was acceptable to the sponsor. The reliability of the rebound hammer was controlled by the quality of the commercial rebound hammer parts used in our design which could not be changed without altering calibration.

Field tests were used to evaluate operational thresholds and perform human factors testing. Operational thresholds were successfully validated for each of the instruments. Human factors testing indicated operational problems with the rebound hammer and the indirect ultrasonic transducer holder that required redesign and modification of each instrument. A new handle and arm brace were added to the rebound hammer to increase diver control. A suction cup was added

to the indirect ultrasonic transducer holder to generate the necessary holding force required to make good contact with the concrete surface. The modifications were completed and tested prior to commencing user tests.

ADM USER TESTS

Description

An operational test and evaluation (OT&E) of the underwater concrete inspection equipment consisting of the rebar locator, rebound hammer, and ultrasonic system was performed in the field by both the Chesapeake Division, Naval Facilities Engineering Command, Code FPO-1 and Underwater Construction Team TWO (UCT-2). The FPO-1 user test was performed on 12-14 January 1988, at the Naval Station, Norfolk, Virginia and the test results are documented in Reference 15. The UCT-2 user test was performed on 4-7 April 1988, at the Naval Construction Battalion Center, Port Hueneme, California and the test results are documented in Reference 16.

The FPO-1 user test was conducted under adverse weather conditions that were very cold, windy, and sometimes wet. The air temperature was 28 to 34 °F and the water temperature was 36 °F. The UCT-2 user test was conducted under good weather conditions. The air temperature was 60 to 80 °F and the water temperature was 58 °F with a slight wind chop.

Test Results

The objective of the user tests was to determine the operational effectiveness of the concrete inspection equipment at fulfilling the mission requirements of FPO-1 and the UCTs under actual working conditions. Human factors testing was also performed during the user tests. Data were collected to evaluate instrument operability, human factors, safety, maintainability, and reliability. Basic measurements of sound velocity, compressive strength, and depth of rebar were taken and recorded. A copy of the test data collected and the human factors evaluation sheets are included in each user test report (Ref 15 and 16).

Overall, the field tests went very well with only minor problems. During the FPO-1 user test, the suction pump on the indirect transducer holder failed due to contamination inside the pump and the handle on the rebound hammer broke due to a poor weld joint. These problems were repaired in time for the UCT-2 user test. No safety problems with the equipment were observed by either FPO-1 or UCT-2. Both users had numerous comments and recommendations for improving and enhancing the design of the underwater concrete inspection equipment. Table 9 summarizes the user test comments on the concrete inspection equipment and lists our recommendations or comments.

After considering the degree to which each comment would enhance the operation of the equipment and the impact it would have on the cost and schedule of procurement, we recommended to the sponsor that all the user recommendations be incorporated into the engineering development model except for the following:

1. The functions of the three data acquisition units could not be combined into one unit.

2. The data acquisition units would be ruggedized and made splashproof but not waterproof.

3. The one-way diver communications system would be improved but not made a two-way link.

4. An improved method for attaching the direct transducer holder to pile surfaces could not be provided.

5. The flexibility of the hose for the rebound hammer could not be improved.

6. Further training and testing could not be held prior to the procurement of the engineering development models.

Although all of the above comments are relevant to enhancing the operation of the equipment, the sponsor agreed that they did not change the operation enough to justify additional funding and the delay of the procurement. Consequently, the major modifications incorporated into the engineering development models based on the user test comments were:

1. A rugged underwater metal shell connector was used in each instrument both on the underwater equipment and the data acquisition units. The connector is identical in all three instruments, which reduces spare parts inventory.

2. A single universal umbilical cable was developed that is common to all three instruments. The umbilical cable is now interchangeable between each instrument, which increases reliability in the field and reduces the volume of equipment.

3. A rugged splashproof housing was developed for each data acquisition unit. All front panel components are sealed, the keypad is waterproofed, and the umbilical cable connector is designed for use underwater.

4. The communications system was improved by increasing the volume range and adding an improved hand microphone at the deck unit.

5. The data acquisition units are packaged with their respective underwater tools.

6. The O&M manuals for each instrument were updated to provide interpretation of the data and to address the limitations of each instrument. The update also covers all changes incorporated into the advanced development models.

7. The underwater connector in the rebar locator was replaced as described in comment 1 above, and the location changed to improve handling characteristics.

8. The underwater air regulator on the rebound hammer was replaced with a much smaller regulator and it was integrated into the handle of the hammer to streamline the design.

9. A much larger carborundum stone for cleaning the surface of the concrete is provided with each instrument along with several spares. The stone has a handle to make it easier for the diver to use.

10. The suction cup design was improved by adding filters to the system and using an improved centrifugal pump.

Another minor change, not commented on during the user tests, was incorporated into the data acquisition units of each instrument. Because some of the data collected during the user tests was obviously bad, a firmware modification was made that allows the operator to decide if the recorded data are valid before storing in memory. If the data are obviously in error, the operator can delete that data point and repeat the measurement, which keeps the bad data point from showing up in the report. This feature should be very helpful in the ultrasonic system where bad data points are sometimes recorded.

CONCLUSIONS

1. Three specialized instruments were developed for the underwater inspection of concrete waterfront structures. This equipment includes a magnetic rebar locator, rebound hammer, and ultrasonic test system:

- The magnetic rebar locator can be used to locate rebar in underwater concrete structures and measure the amount of concrete cover over the rebar.

- The rebound hammer can be used to evaluate the surface hardness of concrete.

- The ultrasonic test system can be used to obtain a general condition rating for the concrete based on sound velocity measurements.

2. Each instrument consists of an underwater sensor connected to a topside deck unit via a buoyant umbilical cable. The battery-powered deck unit contains the signal conditioning electronics and data acquisition system. To operate each instrument, a diver must position the underwater sensor while a person topside operates the deck unit to collect and store data. Each independent instrument provides unique information to help assess the condition of the concrete structure.

3. An advanced development model of each instrument was fabricated for test and evaluation. Developmental tests were successfully completed in the laboratory by NCEL. Operational test and evaluation in the field was performed by both FPO-1 and UCT-2.

4. Two engineering development models of each instrument that implement recommended design changes based on laboratory and user field testing were fabricated for use by the UCTs and other government personnel.

5. The underwater concrete inspection equipment is stored and maintained at OCEI, St. Julians Creek Annex, Portsmouth, Virginia.

6. The underwater concrete inspection equipment does not present an electrical or mechanical safety hazard to the diver during underwater operations.

RECOMMENDATIONS

1. An authorization for Navy use (ANU) should be issued for the rebar locator, rebound hammer, and ultrasonic test system.

2. Only trained or otherwise qualified personnel should collect and interpret data using the rebound hammer and ultrasonic test system.

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Table 1. Rebar Locator System Specifications

Characteristic	Specification
Rebar Locator Underwater Probe	
Weight (in air)	7 pounds
Weight (in water)	3.5 pounds
Operational Depth	190 feet
Operating Temperature Range	28 to 95 °F
Electrical Cable	
Length	200 feet
Weight (in air)	80 pounds
Weight (in water)	8.8 pounds positive bouyancy
Bouyancy	0.044 pound/foot
Cable Reel	
Weight (empty)	65 pounds
Weight (w/cable)	145 pounds
Data Acquisition Unit	
Size (W x L x H)	12 x 18 x 12 inches
Weight	38 pounds
Power Requirements	
Internal Battery Voltage	12 volts direct current (VDC)
Battery Capacity	8 ampere-hours (AH)
Operating Time Between Charges	8 hours
Battery Charger	120 volts alternating current (VAC)
Power Consumption	25 watts
Operating Temperature Range	28 to 120 °F
Humidity	90 percent

Table 2. Rebar Size and Number Chart

Rebar Size (Inches OD)	Rebar Number
3/8	03
1/2	04
5/8	05
3/4	06
7/8	07
1	08
1-1/8	09
1-1/4	10
1-3/8	11
1-1/2	12
1-5/8	13
1-3/4	14
1-7/8	15
2	16

Table 3. Rebound Hammer System Specifications

Characteristic	Specification
Rebound Hammer Underwater Unit	
Weight (in air)	12 pounds
Weight (in water)	5 pounds
Operational Depth	190 feet
Operating Temperature Range (in water)	28 to 95 °F
Electrical Cable	
Length	200 feet
Weight (in air)	80 pounds
Weight (in water)	9 pounds positive bouyancy
Bouyancy	0.044 pound/foot
Cable Reel	
Weight (empty)	65 pounds
Weight (w/cable)	145 pounds
Data Acquisition Unit	
Size (W x L x H)	12 x 18 x 12 inches
Weight	38 pounds
Power Requirements	
Internal Battery Voltage	18 volts direct current (VDC)
Battery Capacity	8 ampere-hours
Operating Time Between Charges	8 hours
Battery Charger	120 volts alternating current (VAC)
Power Consumption	50 watts
Operating Temperature Range	28 to 120 °F
Humidity	90 percent

Table 4. General Condition Rating Based on Sound Velocity

Condition Rating	Sound Velocity (ft/sec)
Excellent	>15,000
Good	12,000 - 15,000
Questionable	10,000 - 12,000
Poor	7,000 - 10,000
Very Poor	<7,000

Table 5. Ultrasonic Test System Specifications

Characteristic	Specification
Direct Transducer Holder	
Weight (in air)	29 pounds
Weight (in water)	1 pound
Operational Depth	190 feet
Operating Temperature Range (in water)	28 to 95 °F
Storage Temperature Range	0 to 140 °F
Operating Frequency	50 kilohertz (kHz)
Indirect Transducer Holder	
Weight (in air)	12 pounds
Weight (in water)	3 pounds
Operational Depth	190 feet
Operating Temperature Range (in water)	28 to 95 °F
Storage Temperature Range	0 to 140 °F
Operating Frequency	50 kHz
Electrical Cable	
Length	200 feet
Weight (in air)	80 pounds
Weight (in water)	9 pounds positive buoyancy
Buoyancy	0.044 pounds/foot
Cable Reel	
Weight (empty)	65 pounds
Weight (with cable)	145 pounds
Data Acquisition Unit	
Size (W x L x H)	12 x 18 x 12 inches
Weight	47 pounds
Power Requirement	
Battery Voltage	18 volts direct current (VDC)
Battery Capacity	8 ampere-hour (Ah)
Operating Time Between Charges	8 hours
Battery Charger	120 volts alternating current (VAC)
Power Consumption	50 watts
Operating Temperature Range	28 to 120 °F
Storage Temperature Range	0 to 140 °F
Humidity	90 percent

Table 6. Summary of the Developmental Test Results for the Rebar Locator

Test Parameter	TEMP Threshold	Measured Value
Physical Characteristics (1)		
Rebar Locator		
Weight in air	10 pounds	7 pounds
Weight in water	neutral	3.5 pounds
Data Acquisition Unit Weight	40 pounds	25 pounds
Umbilical Cable Buoyancy	neutral	+0.09 lb/ft
Accuracy		
Concrete Cover	±12 percent	±5 percent
Operational Depth	85 psi (190 ft)	100 psi
Cold Operating Temperature (2)		
Dry	10 °F (±4)	20 °F
Submerged	28 °F (±4)	30 °F
Reliability	0.9	0.9
Operational Thresholds		
Scan Time	2 minutes	30 seconds
Instrument Positioning Time	1 minute	1 minute
Setup/Packup Time	4 hours	1 hour
Relocation Time	1 hour	30 minutes

Comments:

(1) No attempt was made to change the physical characteristics of the rebar locator to match the thresholds specified in the TEMP before conducting subsequent user tests. Our initial field tests did not detect any major handling or operational problems with the system as it was designed. All further design changes were based on user recommendations.

(2) The data acquisition unit in the rebar locator did not meet the minimum low operating temperature requirement specified in the TEMP but was still accepted by the sponsor.

Table 7. Summary of the Developmental Test Results for the Rebound Hammer

Test Parameter	TEMP Threshold	Measured Value
Physical Characteristics (1)		
Rebound Hammer		
Weight in air	10 pounds	12 pounds
Weight in water	neutral	5 pounds
Data Acquisition Unit Weight	40 pounds	26 pounds
Umbilical Cable Buoyancy	neutral	+0.08 lb/ft
Accuracy		
Surface Hardness	±5 percent	±6 percent
Operational Depth	85 psi (190 ft)	100 psi
Cold Operating Temperature (2)		
Dry	10 °F (±4)	20 °F
Submerged	28 °F (±4)	30 °F
Reliability (3)	0.9	0.88
Operational Thresholds		
Scan Time	1 minute	30 seconds
Instrument Positioning Time	1 minute	1 minute
Setup/Packup Time	4 hours	1.5 hour
Relocation Time	1 hour	1 hour

Comments:

(1) No attempt was made to change the physical characteristics of the rebound hammer to match the thresholds specified in the TEMP before conducting subsequent user tests. Our initial field tests did not detect any major handling or operational problems with the system as it was designed. All further design changes were based on user recommendations.

(2) The data acquisition unit in the rebound hammer did not meet the minimum low operating temperature requirement specified in the TEMP but was still accepted by the sponsor.

(3) The measured reliability of the rebound hammer did not quite meet the TEMP threshold but we recommended this value be accepted because of the quality of the commercial parts being used.

Table 8. Summary of the Developmental Test Results for the Ultrasonic System

Test Parameter	TEMP Threshold	Measured Value
Physical Characteristics (1)		
Indirect Scanner		
Weight in air	25 pounds	18 pounds
Weight in water	5 pounds	0.5 pound
Direct Scanner		
Weight in air	25 pounds	29 pounds
Weight in water	5 pounds	0.5 pound
Data Acquisition Unit Weight	40 pounds	28 pounds
Umbilical Cable Buoyancy	neutral	+0.05 lb/ft
Accuracy		
Homogeneity of Concrete	±10 percent	±3 percent
Operational Depth	85 psi (190 ft)	100 psi
Cold Operating Temperature (2)		
Dry	10 °F (±4)	20 °F
Submerged	28 °F (±4)	30 °F
Reliability	0.9	0.9
Operational Thresholds		
Scan Time	2 minutes	30 seconds
Instrument Positioning Time	2 minutes	1 minute
Setup/Packup Time	4 hours	1 hour
Relocation Time	1 hour	45 minutes

Comments:

(1) No attempt was made to change the physical characteristics of the ultrasonic system to match the thresholds specified in the TEMP before conducting subsequent user tests. Our initial field tests did not detect any major handling or operational problems with the system as it was designed. All further design changes were based on user recommendations.

(2) The data acquisition unit in the ultrasonic system did not meet the minimum low operating temperature requirement specified in the TEMP but was still accepted by the sponsor.

Table 9. User Test Comments

System Component	User: FPO-1/CHILDS	User: UCT-2	Comments and/or Recommendations
I. General a. Cable	Replace with neutral or negatively buoyant cable.	Prefer positively buoyant cable.	Plan to decrease buoyancy by increasing size of some conductor but cable will still be positively buoyant.
	Modify cable connectors.	Improve cable connectors.	Plan to make all connectors identical and easier to connect.
	Eliminate hose reel and coil in a box.	Prefer hose reel built into shipping container.	Plan to retain reel in shipping container design. User can remove for operation if desired.
	Provide universal cable for all 3 tools to cut down on equipment volume.	Provide interchangeable cables.	Will be done by modifying design drawings and specs.
b. Data Acquisition Unit	Improve housing to be more rugged and waterproof.	Improve housing to be more rugged and waterproof.	Requires changing power supply for charging batteries. Will incorporate into design drawings and specs. (Splash proof)
	Incorporate two-way communications with headset and microphone for topside use and throat mike for diver.	Improve comm by increasing volume range and improve diver earphone. Two-way comm not considered a requirement.	Will improve existing one-way communications link by increasing gain and improving diver earphone; incorporate into design drawings and specs. Development of a two-way diver comm system is beyond the scope of this project; requires more funding and time.

Table 9. User Test Comments (Continued)

System Component	User: FPO-1/CHILDS	User: UCT-2	Comments and/or Recommendations
	Combine DAUs for all tools into single unit.	No comment.	This will require extensive redesign, development and testing. Will delay procurement at least 6 months. Recommend no change to DAU design at this time.
	No comment.	Package each DAU with its respective U/W tool.	Still under consideration; could be a moisture/humidity problem.
c. Operations	Address limitations of each instrument in the O&M manuals.	Provide instructions to interpret each instrument's data.	Plan to add section to O&M manuals addressing data interpretation and limitations.
	Recommend special training for user of rebound hammer and ultrasonic equipment.	No comment.	Still under consideration; additional funding required to setup special training.
	No comment.	Provide operator checklists for setup and breakdown of instruments.	Plan to add checklists in the O&M manuals.
II. <u>Rebar Locator</u>	Location of umbilical cable connection to rebar locator not satisfactory.	Improve cable connectors.	Plan to bring cable into rebar locator from top instead of from bottom and change connectors.
	No additional field tests required	Perform additional field tests.	Requires more 6.3 funding and time.
III. <u>Rebound Hammer</u>	Make air regulator more compact.	No comment (we changed position of regulator for UCT-2 tests).	Plan to use a smaller regulator and change its location to streamline design.

Table 9. User Test Comments (Continued)

System Component	User: FPO-1/CHILDS	User: UCT-2	Comments and/or Recommendations
	No comment.	Provide larger forearm strap.	Plan to modify design drawings and specs to provide larger strap.
	Redesign handle that broke.	No comment.	Handle has been modified.
	No comment.	Add 10-ft section of more flexible hose at instrument.	Flexibility cannot be improved because of the electrical cable inside the polyurethane tube.
	Carborundum stone was not adeq[illegible].	No comment (provide larger stone).	Plan to provide larger improved stone for cleaning.
	Perform more extensive field tests.	Same comment.	This will require more 6.3 funds
IV. Ultrasonic System	Strengthen handles on the direct XDUCER holder.	No comment.	Plan to modify design drawings to increase strength.
	No comment.	Improve attachment method for direct transducer holder.	Requires additional funding and time; difficult problem.
	Increase spacing between handles on indirect XDUCER holder.	No comment.	Plan to modify design drawings to increase spacing.
	Improve suction cup (failed during test).	Improve suction cup on indirect holder. (Actually was corrected in field during user tests.)	Minor adjustments have been made to improve holding force.
	Coat syntactic foam to prevent damage.	Same comment.	Plan to coat foam with urethane or similar coating.
	Perform more extensive field tests.	Same comment.	This will require more 6.3 funding.

Figure 1. Commercial R-Meter.

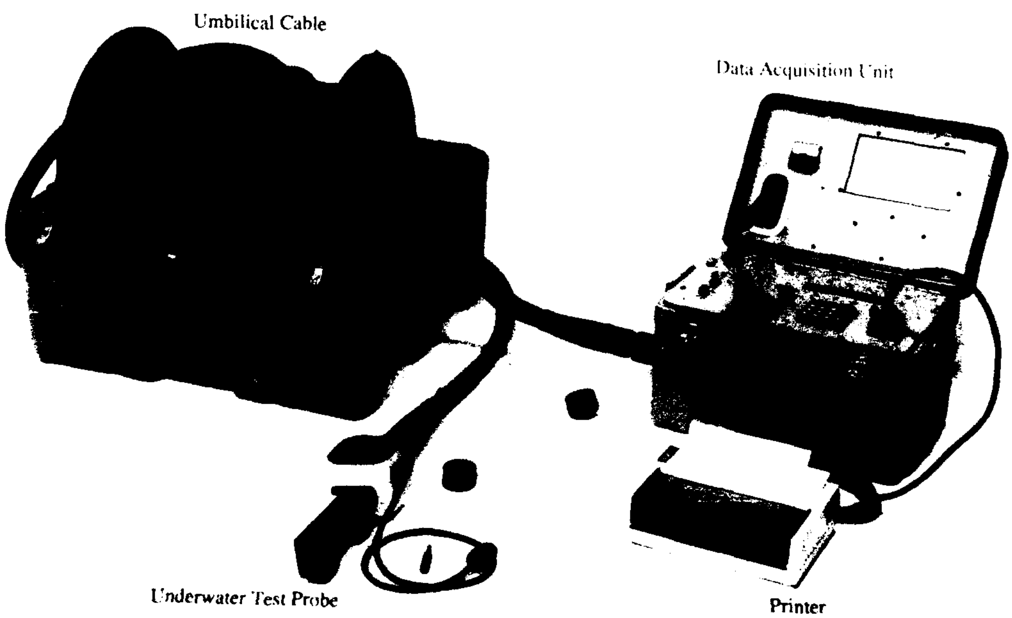


Figure 2. Underwater rebar locator system.

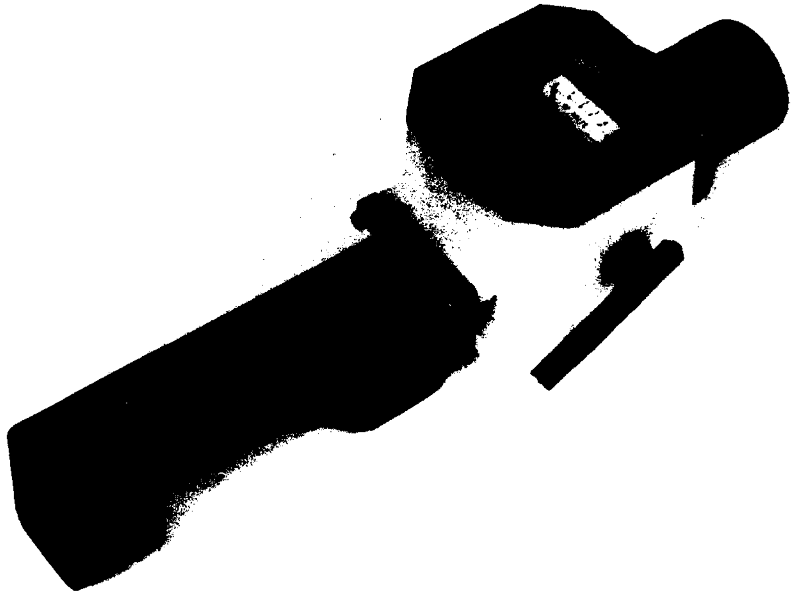


Figure 3. Underwater test probe.

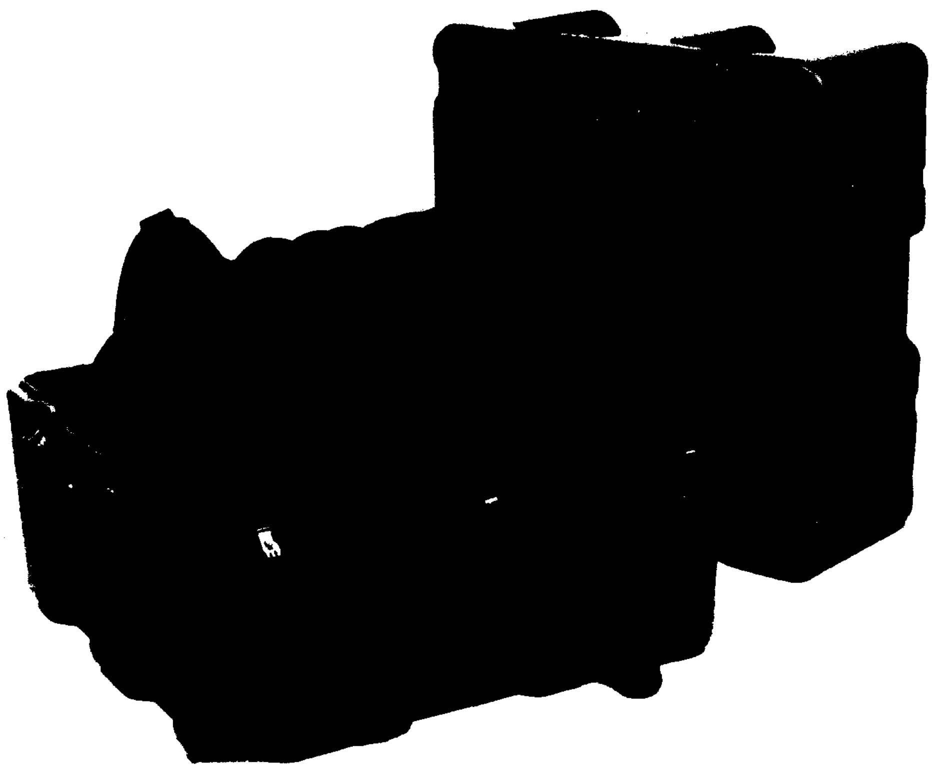


Figure 4. Umbilical cable.

Figure 5. Rebar locator DAU.

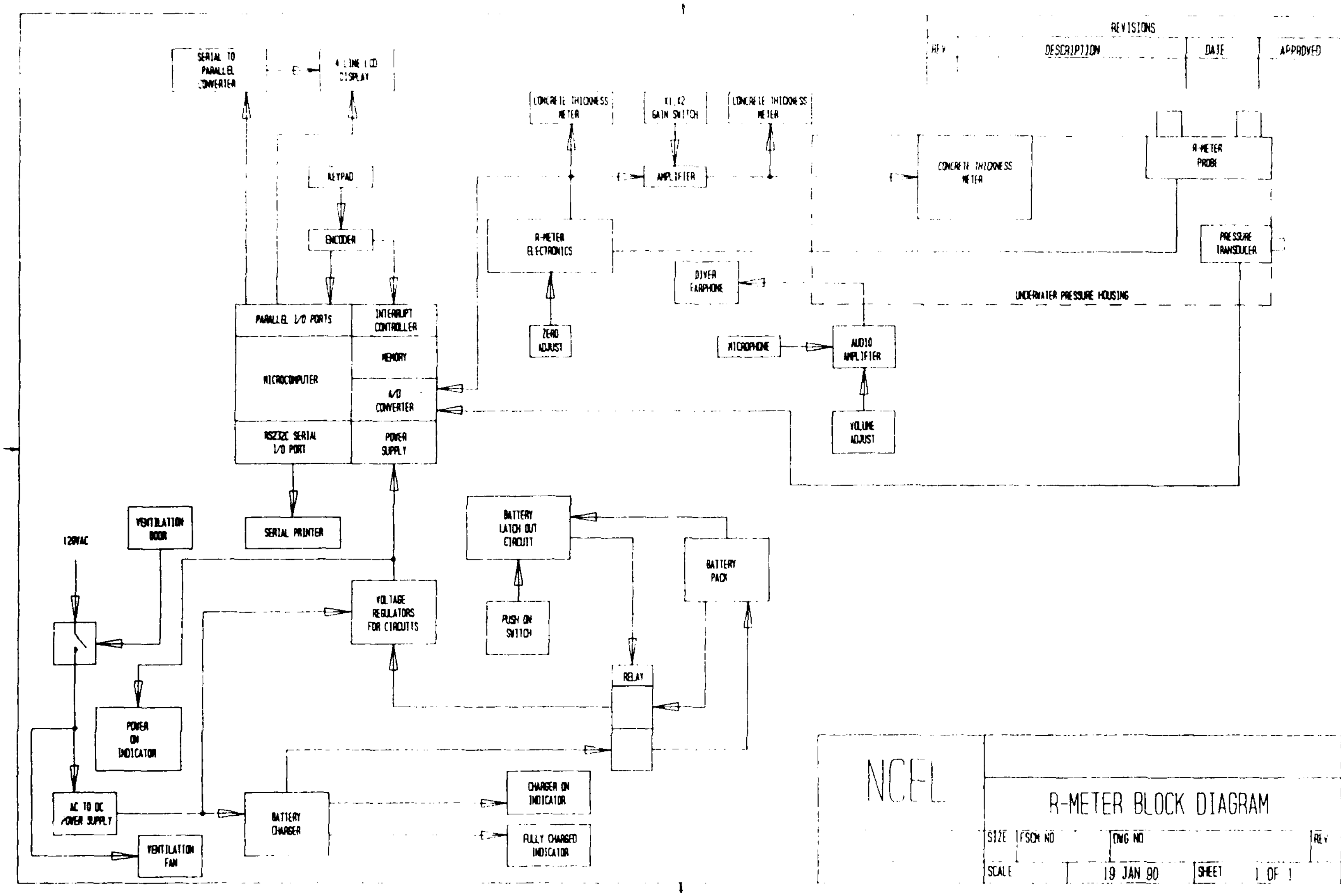


Figure 6. Rebar locator block diagram.

Activity:NCEL REBAR LOCATOR
Facility Name:CHK OUT
Property Record number:NA
Date: 5-9-90

LOCATION	DEPTH (ft)	REBAR SIZE (number)	CONCRETE COVER (inches)
1-596	0	5	1 .5
2-596	0	5	4 .4
3-596	0	5	5 .5
4-596	1	5	5 .5
5-596	0	5	3 .5
6-596	0	5	3 .4
6-596	1	5	3 .3
7-596	0	5	1 .6
8-596	0	5	1 .6
8-596	1	5	3 .6
9-596	1	5	3 .6

Figure 7. Rebar locator data printout.

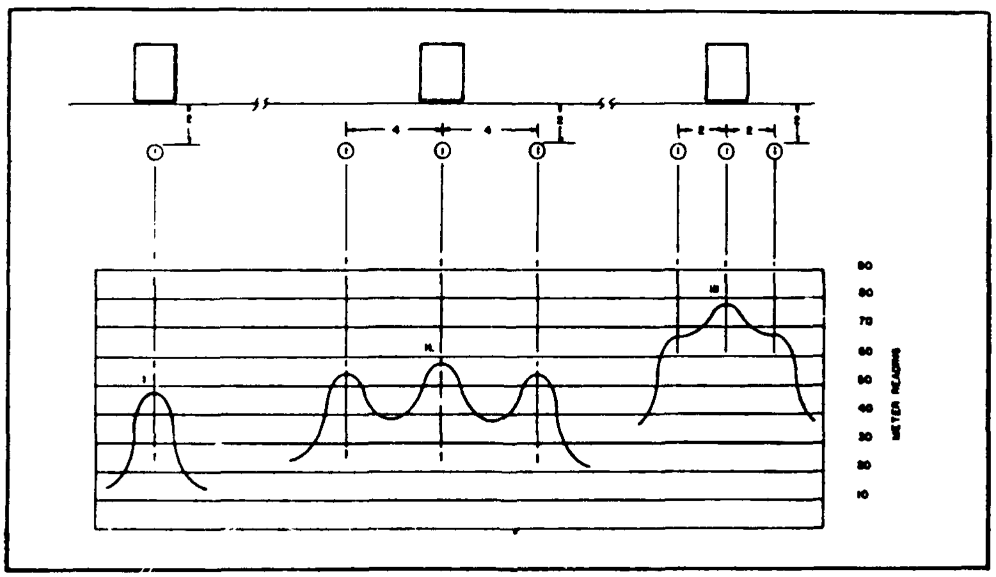


Figure 8. Parallel rebar effect.

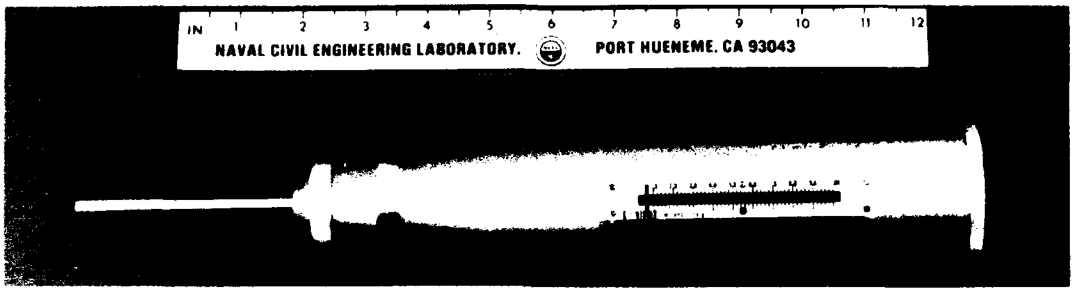


Figure 9. Commercial H-Meter.

Parts List

1 - Cap
2 - Pressure spring
3 - Pawl spring
4 - Guide flange
5 - Pointer guide rod
6 - Rebound reading pointer
7 - Hammer
8 - Guide rod
9 - H-Meter housing
10 - Percussion spring
11 - Plunger head
12 - Shock-absorber spring
13 - Spring fastening sleeve
14 - Two-part pressure ring
15 - Threaded ring nut
16 - Dust sealing ring
17 - Pawl
18 - Push-button bush
19 - Push-button
20 - Push-button pin
21 - Push-button spring
22 - Abrasive stone
23 - Self adhesive sticker with P.S.I. scale
24 - Graduated plate
25 - Complete case
26 - Lock nut
27 - Regulation screw
28 - Pawl pin

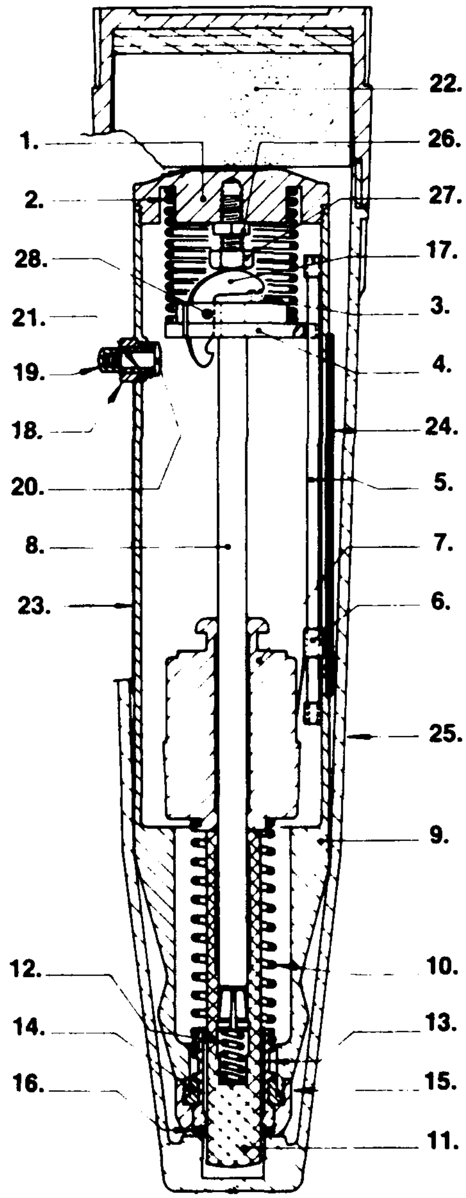


Figure 10. Cross-section view of H-Meter, Model C-7312.

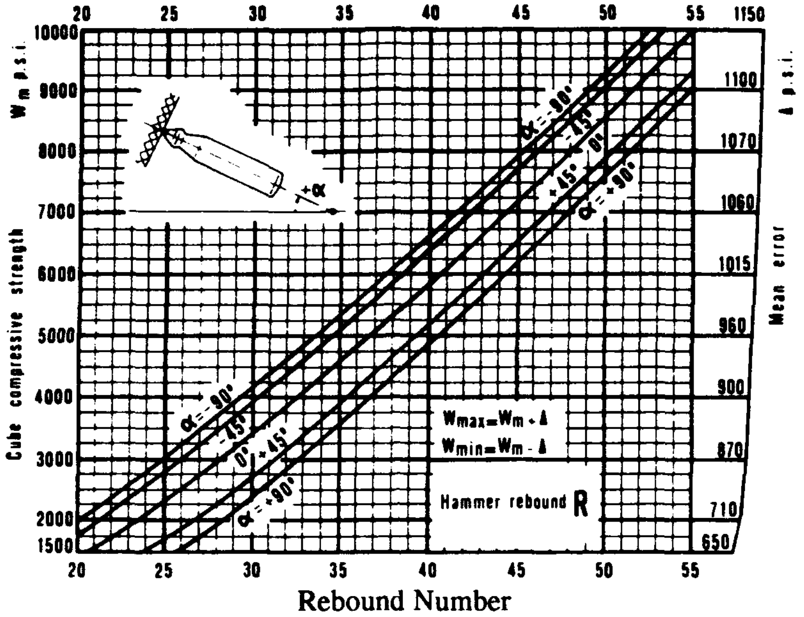


Figure 11. H-Meter calibration chart.

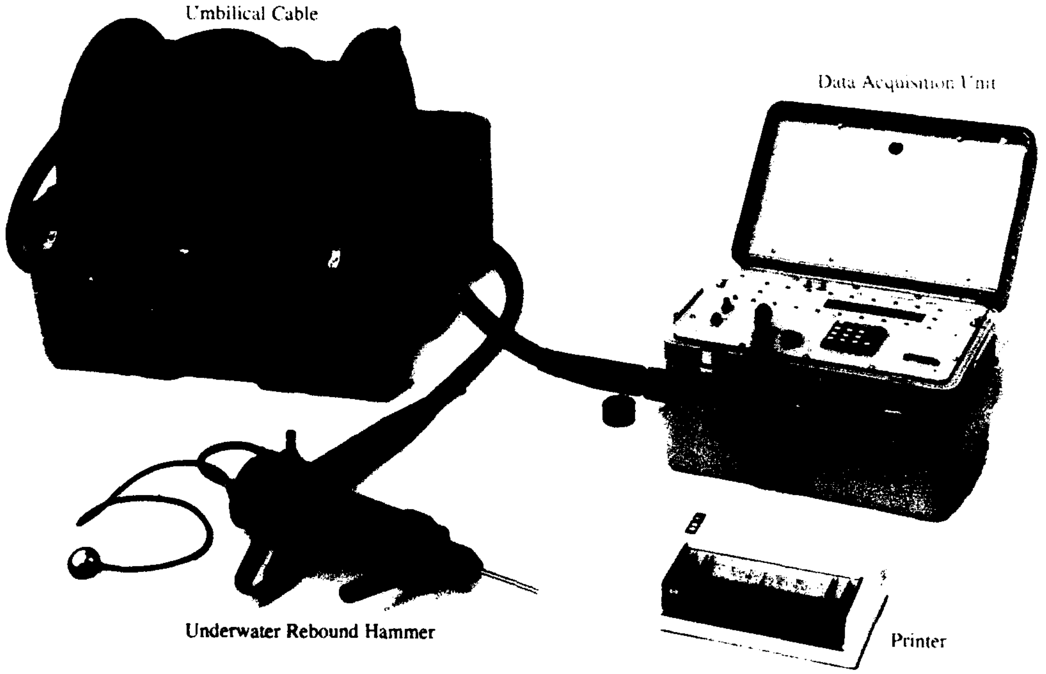


Figure 12. Underwater rebound hammer system.

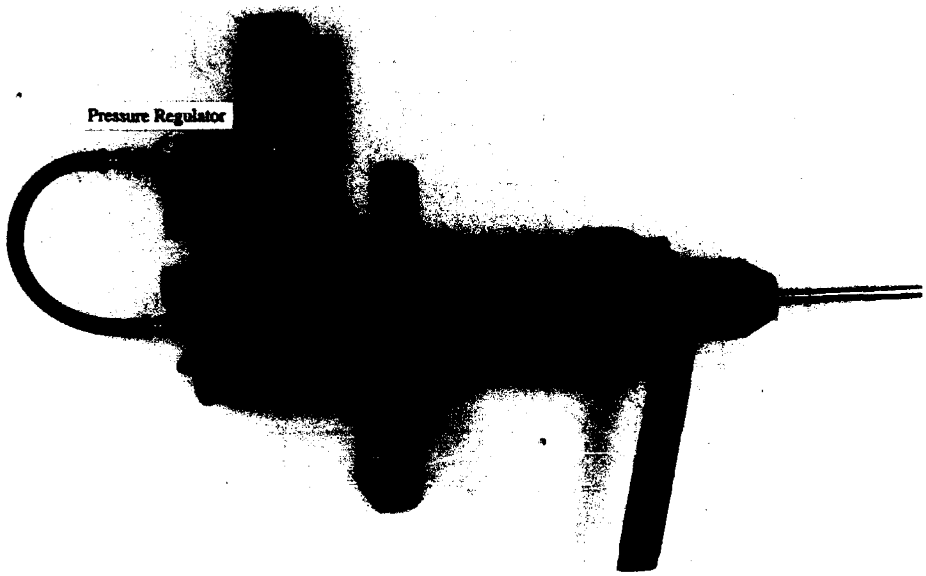


Figure 13. Underwater rebound hammer.

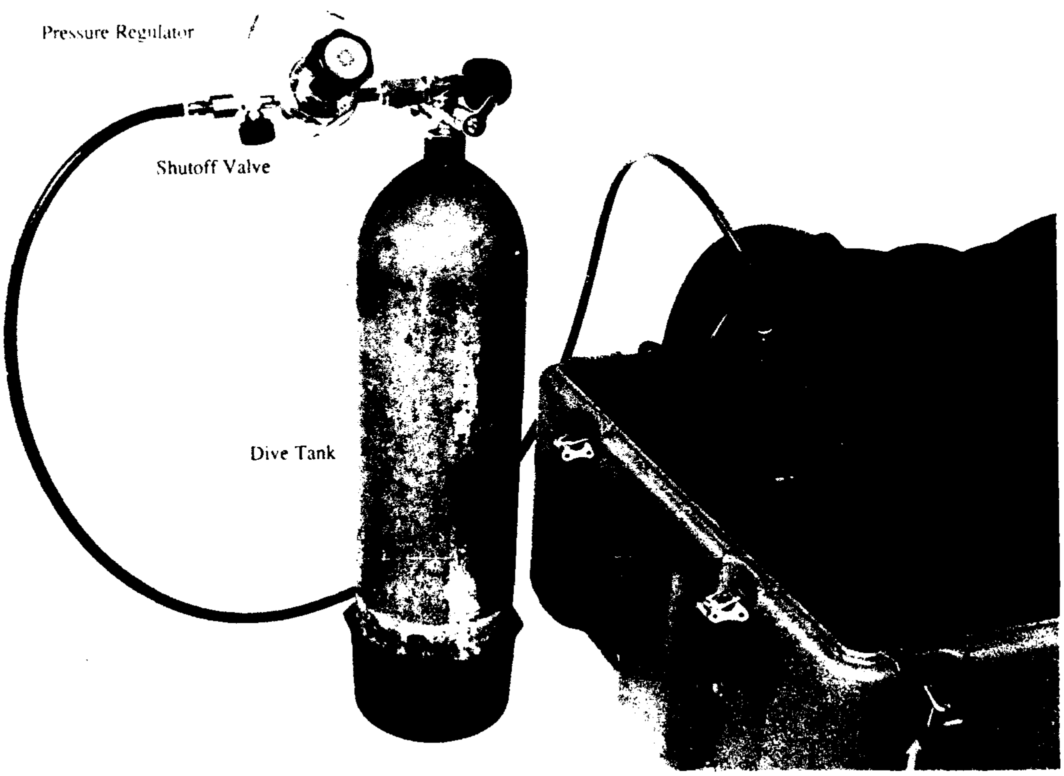


Figure 14. Dive tank for supplying air to umbilical cable.

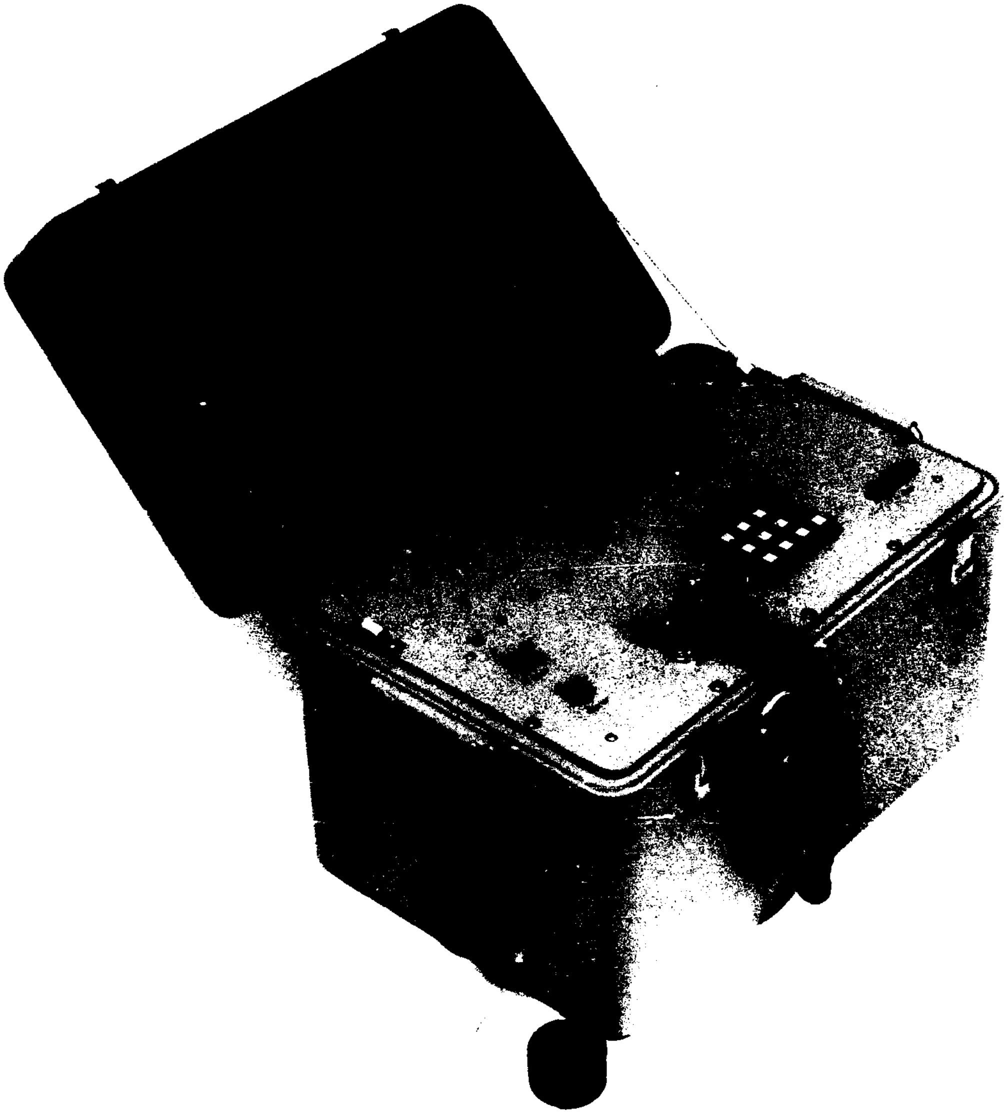


Figure 15. Rebound hammer DAU.

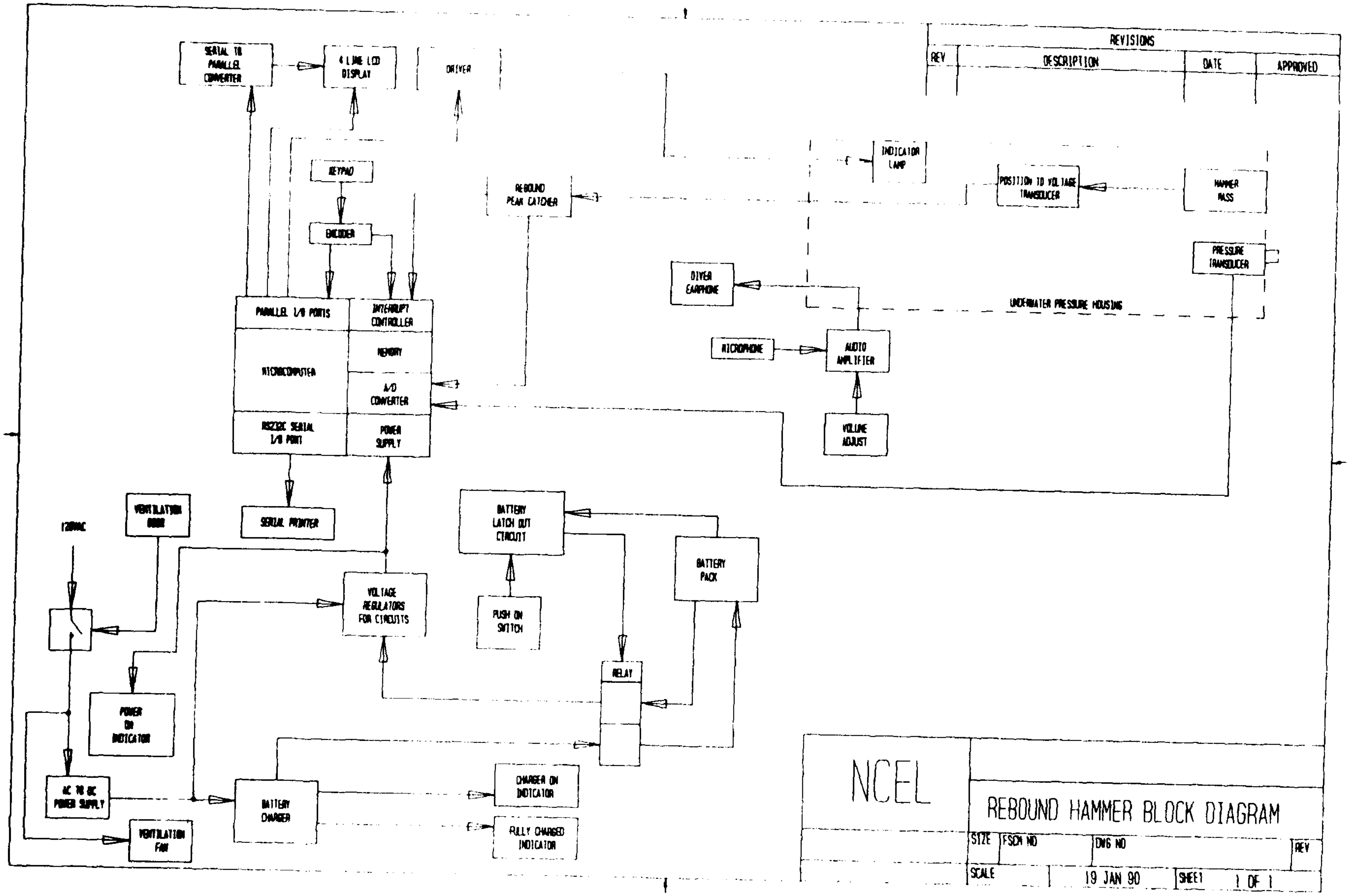


Figure 16. Rebound hammer block diagram.

Activity:NCEL REBOUND HAMMER
Facility Name:CHK OUT
Property Record number:1
Date: 5-14-90

LOCATION (CAL NO)	DEPTH (ft)	REBOUND (mean)	STD DEV	REBOUND CORRECTED	EST STREN (psi)	SAMPLES (N)
1	CAL	78	1			12
2	CAL	79	0			12
1-596	0	43	2	43	7654	12
2-596	24	45	4	45	8115	12
3-596	0	45	2	45	8061	12
4-596	0	45	2	45	8088	12
5-596	0	44	5	45	8006	12
6-596	0	41	3	42	7172	12
6-596	1	38	1	38	6332	12

Strength values are estimates only,
please refer to the O&M manual for interpretation

Figure 17. Rebound hammer data printout.

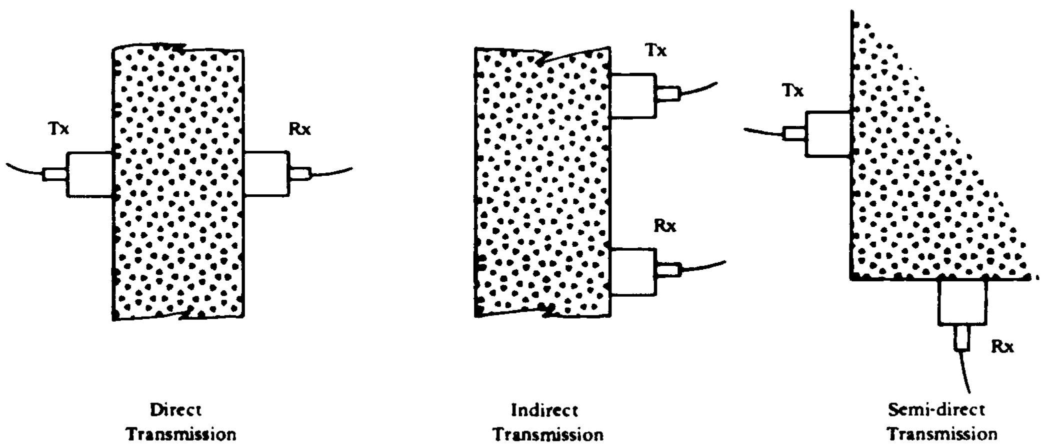


Figure 18. Methods of ultrasonic pulse transmission.

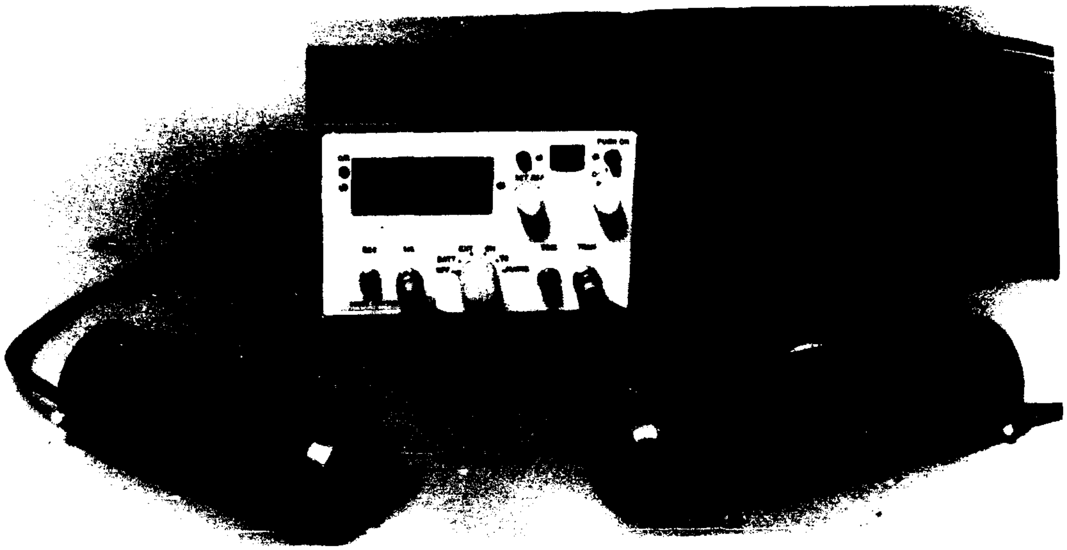


Figure 19. Commercial V-Meter.

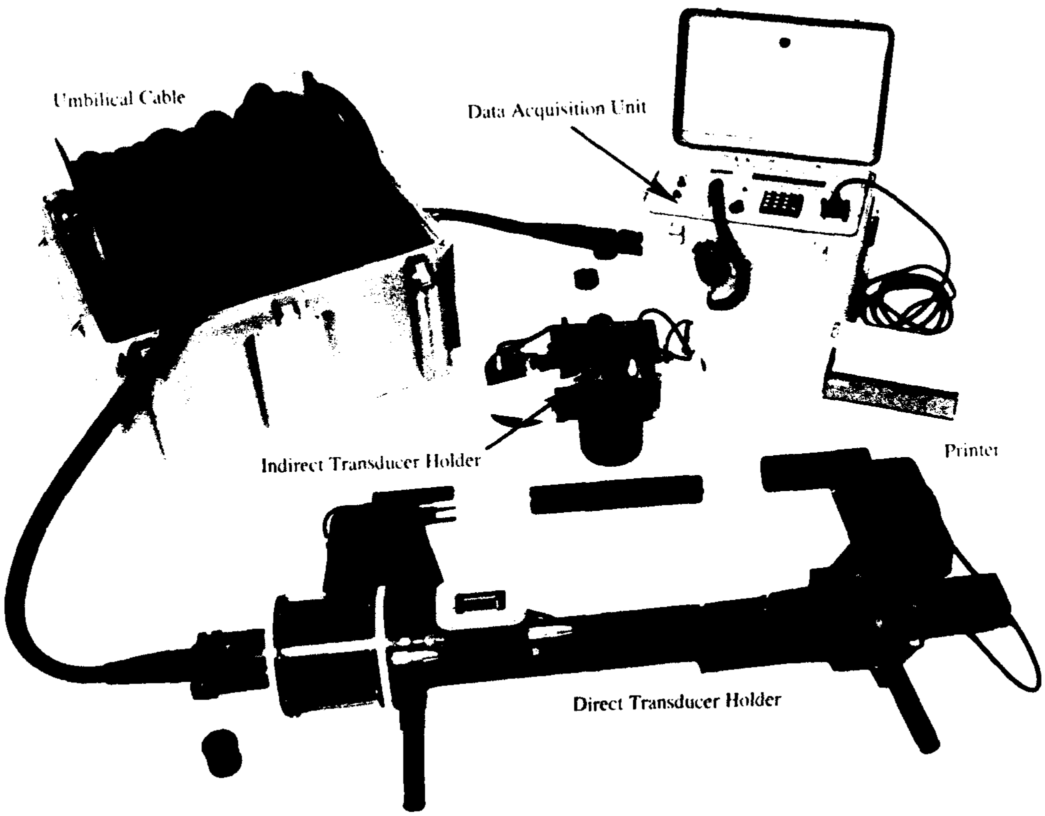


Figure 20. Underwater ultrasonic test system.

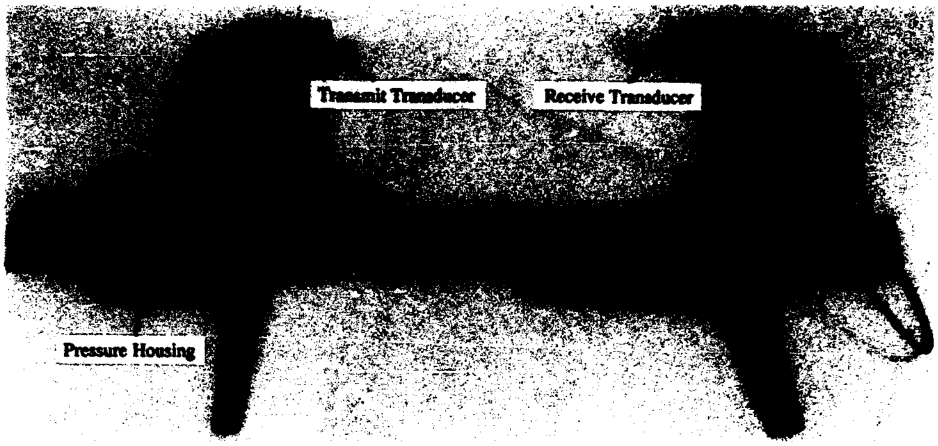


Figure 21. Direct transducer holder.

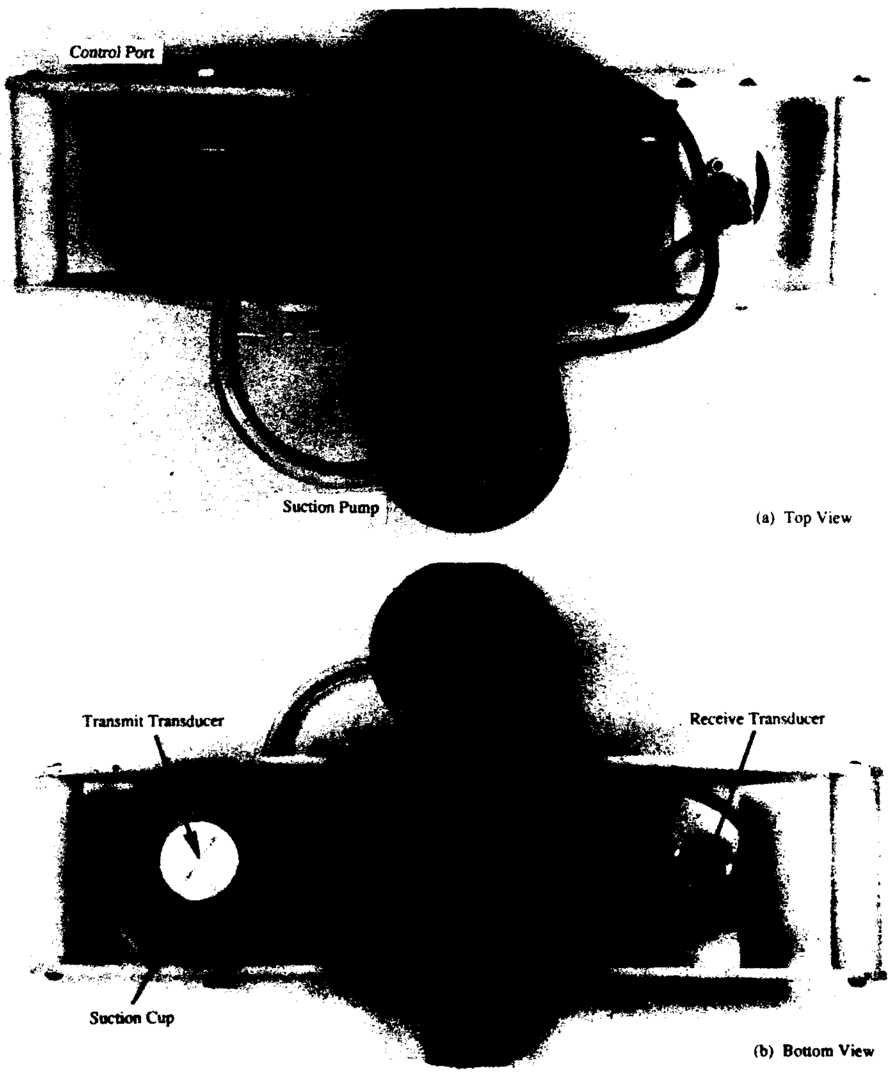


Figure 22. Indirect transducer holder.

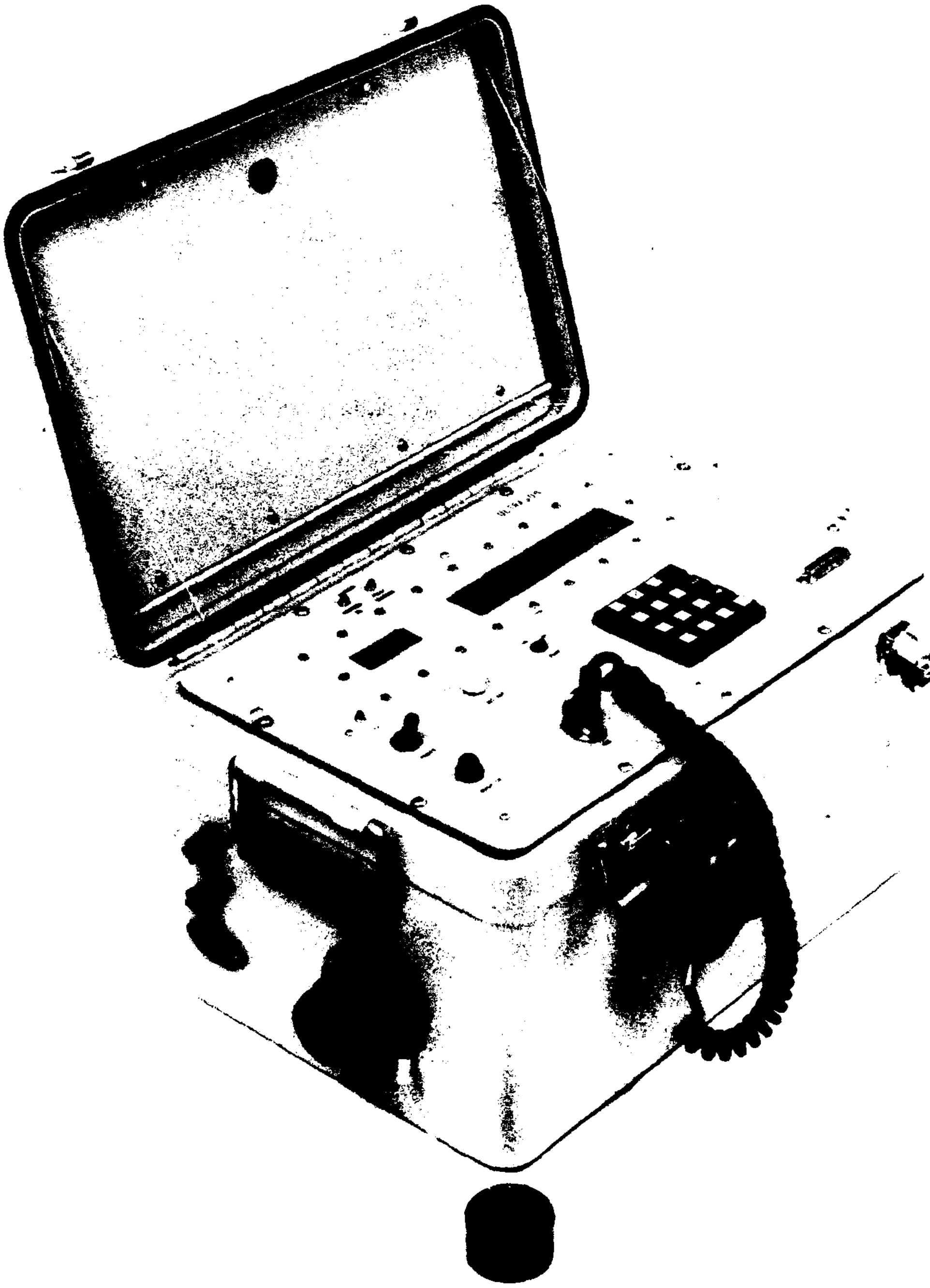


Figure 23. Ultrasonic test system DAU.

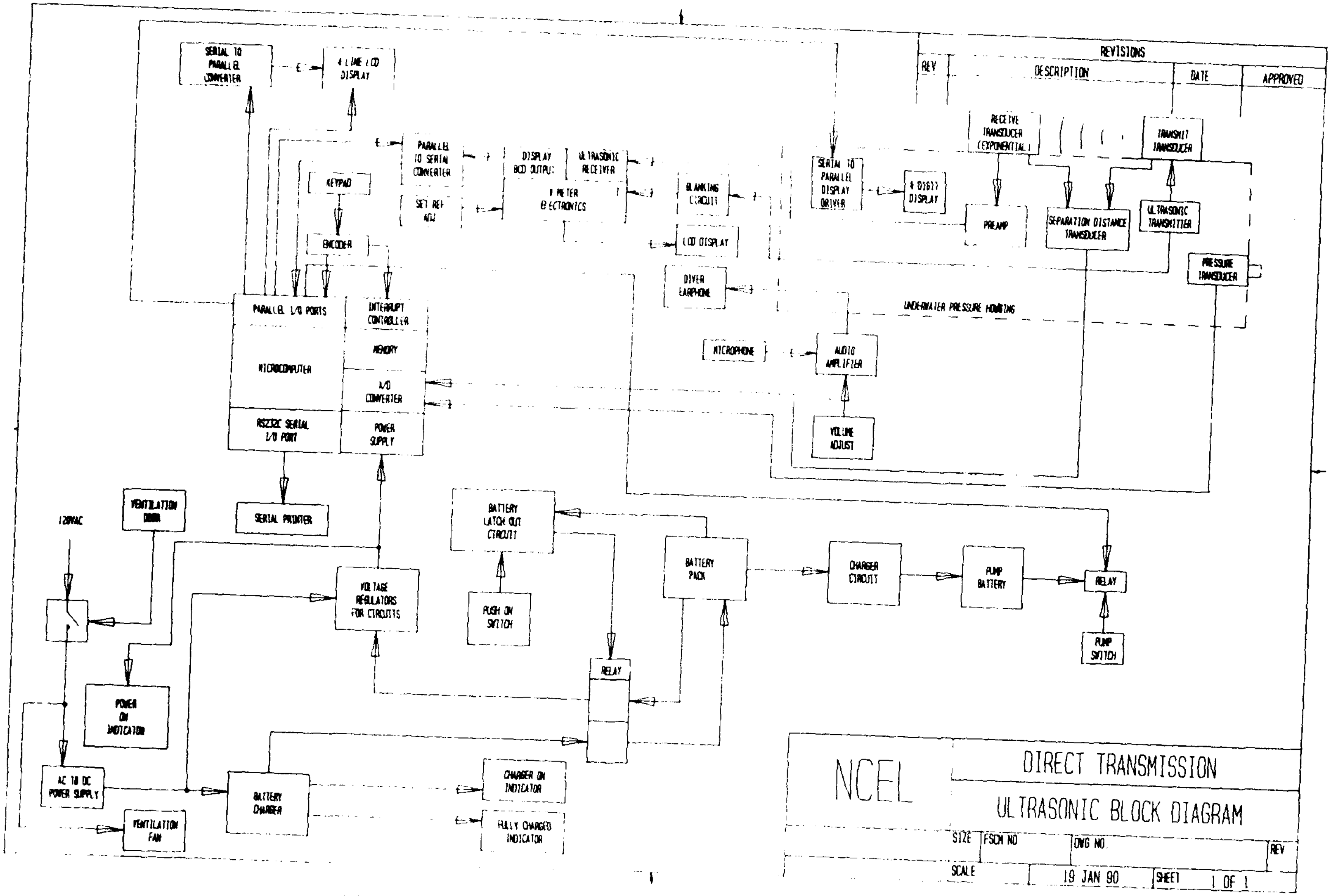


Figure 24. Ultrasonic system block diagram - direct transmission.

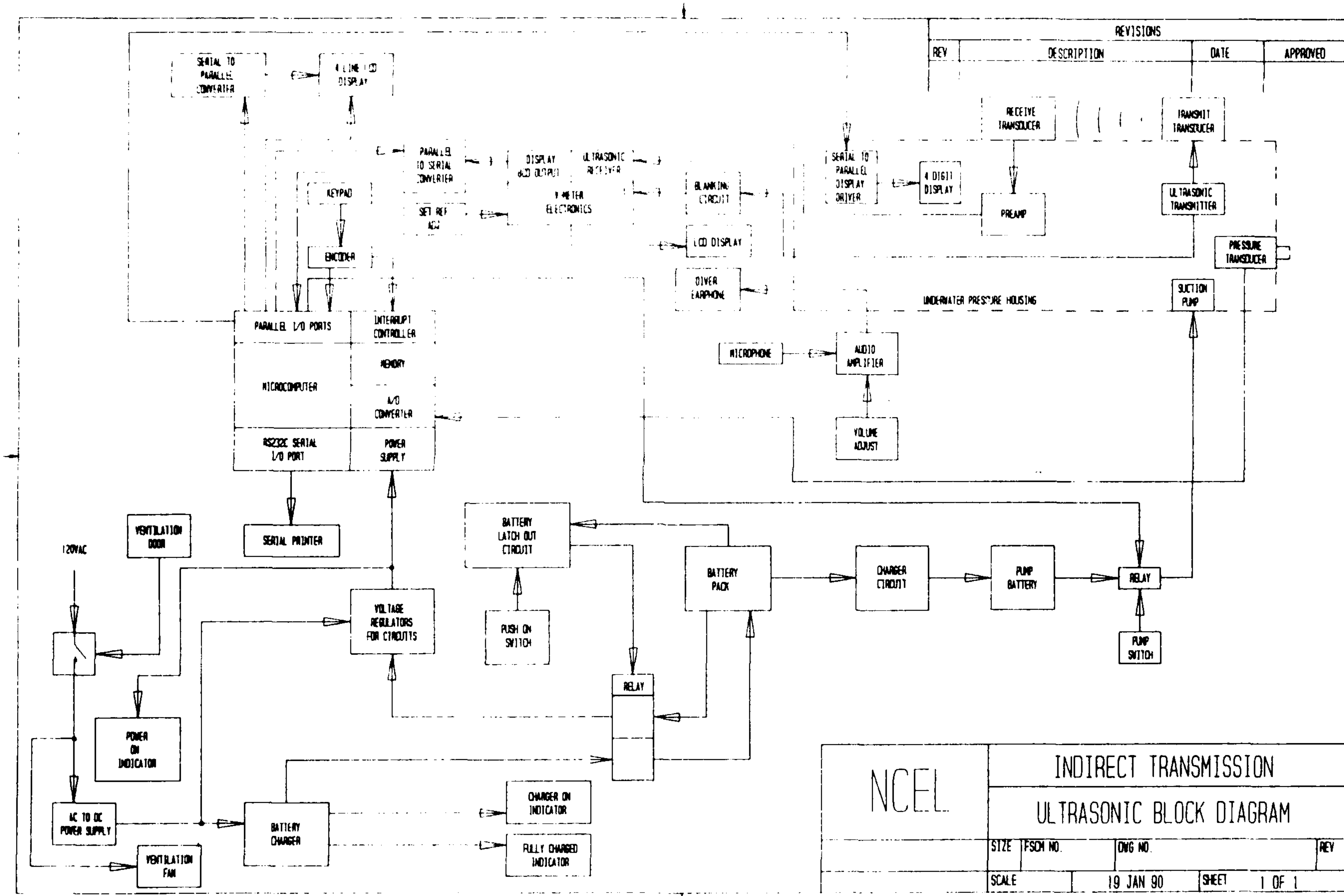


Figure 25. Ultrasonic system block diagram - indirect transmission.

Activity:NCEL ULTRASONIC TESTER
Facility Name:CHK OUT
Property Record number:1
Date: 5-10-90

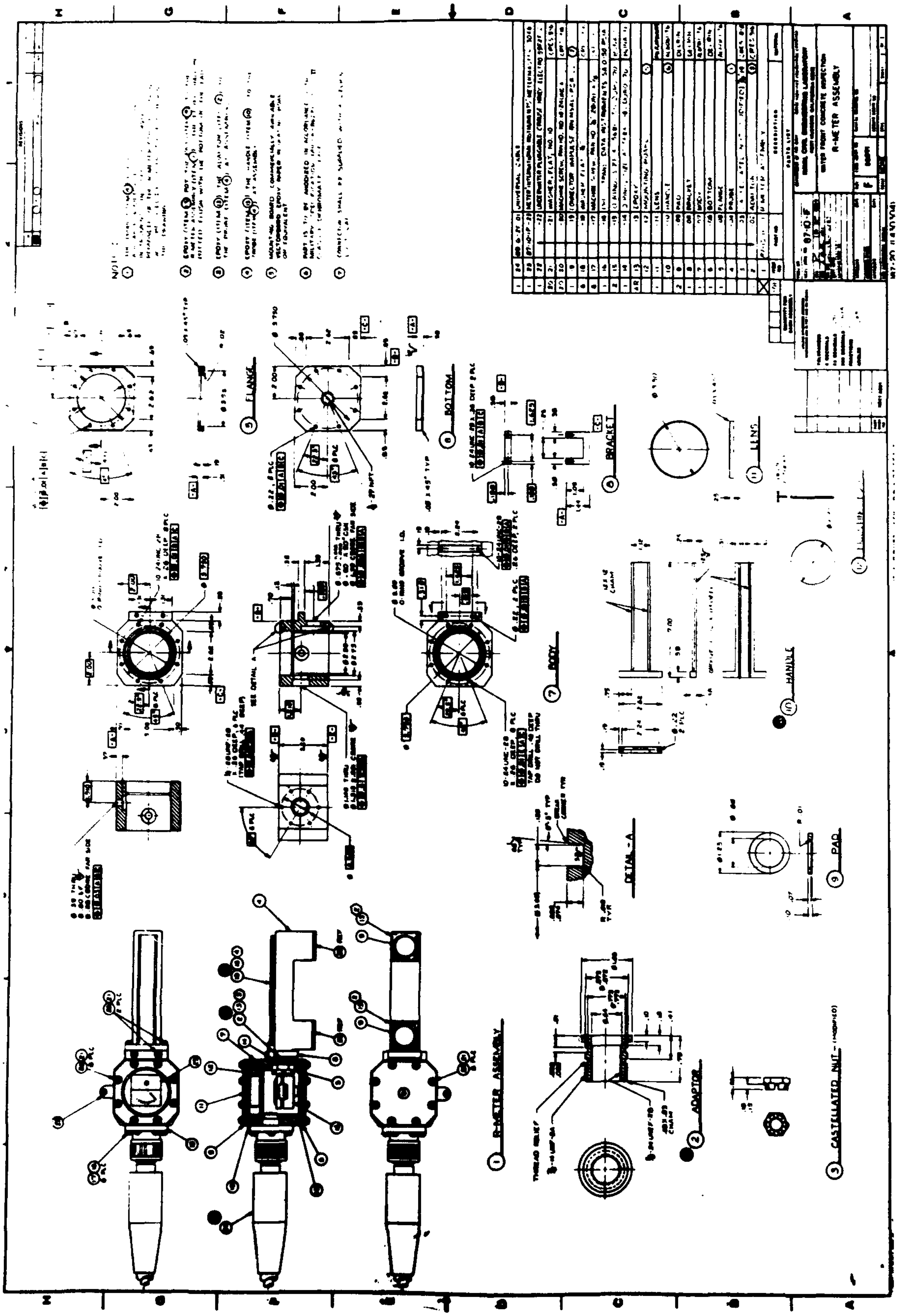
LOCATION	DEPTH (ft)	TIME (microsec)	LENGTH (in)	SOUND VEL (ft/sec)	CONCRETE RATING	TYPE
1-59E	1	105	12	9523	Poor	I
3-59E	1	145	12	6896	Very poor	I
3-59E	1	103	12	9708	Poor	I
4-59E	0	53	12	20130	Excellent	D
5-59E	0	51	12	20766	Excellent	D
6-59E	20	73	12	14623	Good	D
7-59E	0	51	12	20844	Excellent	D
8-59E	0	52	12	20360	Excellent	D
9-59E	0	51	12	20824	Excellent	D

Concrete Rating is an estimate only,
please refer to the O&M manual for interpretation.
D=Direct Transmission I=Indirect Transmission

Figure 26. Ultrasonic system data printout.

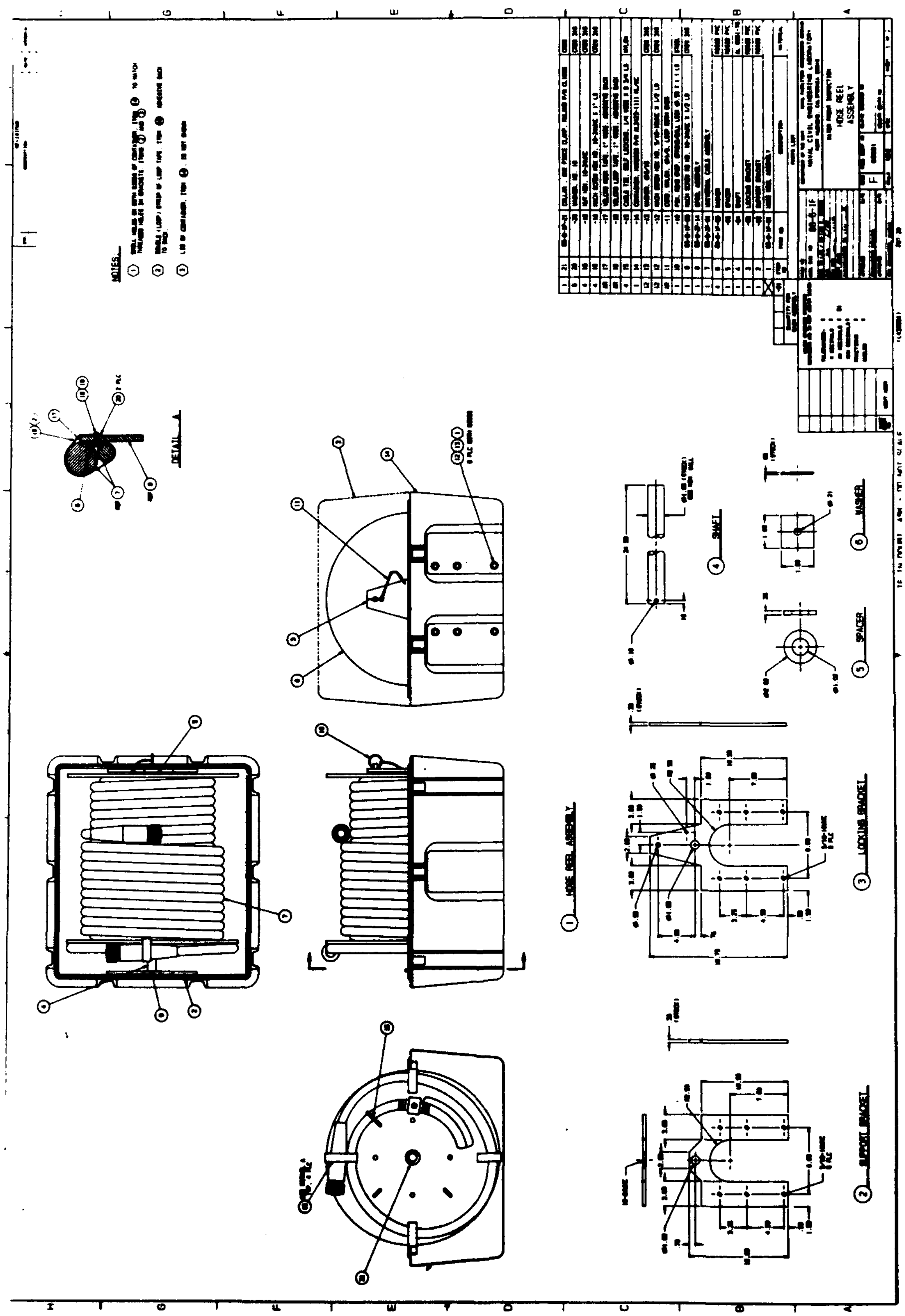
Appendix A

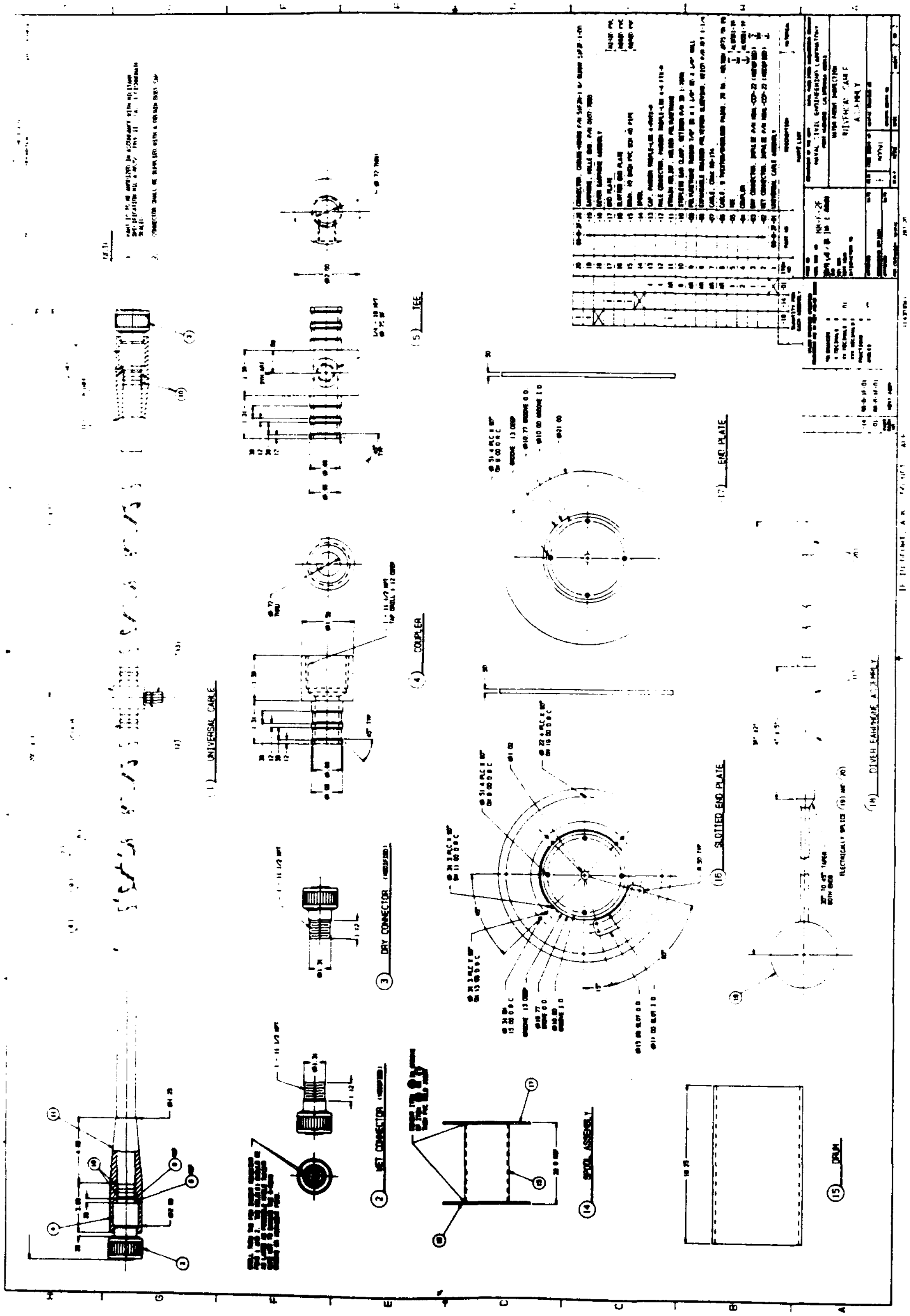
MECHANICAL DESIGN DRAWING
FOR
REBAR LOCATOR


R-METER ASSEMBLY
ADAPTOR
CASTELLATED NUT
DETAIL - A
PAD
FLANGE
BOTTOM
BRACKET
BODY
LENS
HANDLE
R-METER ASSEMBLY

Appendix B

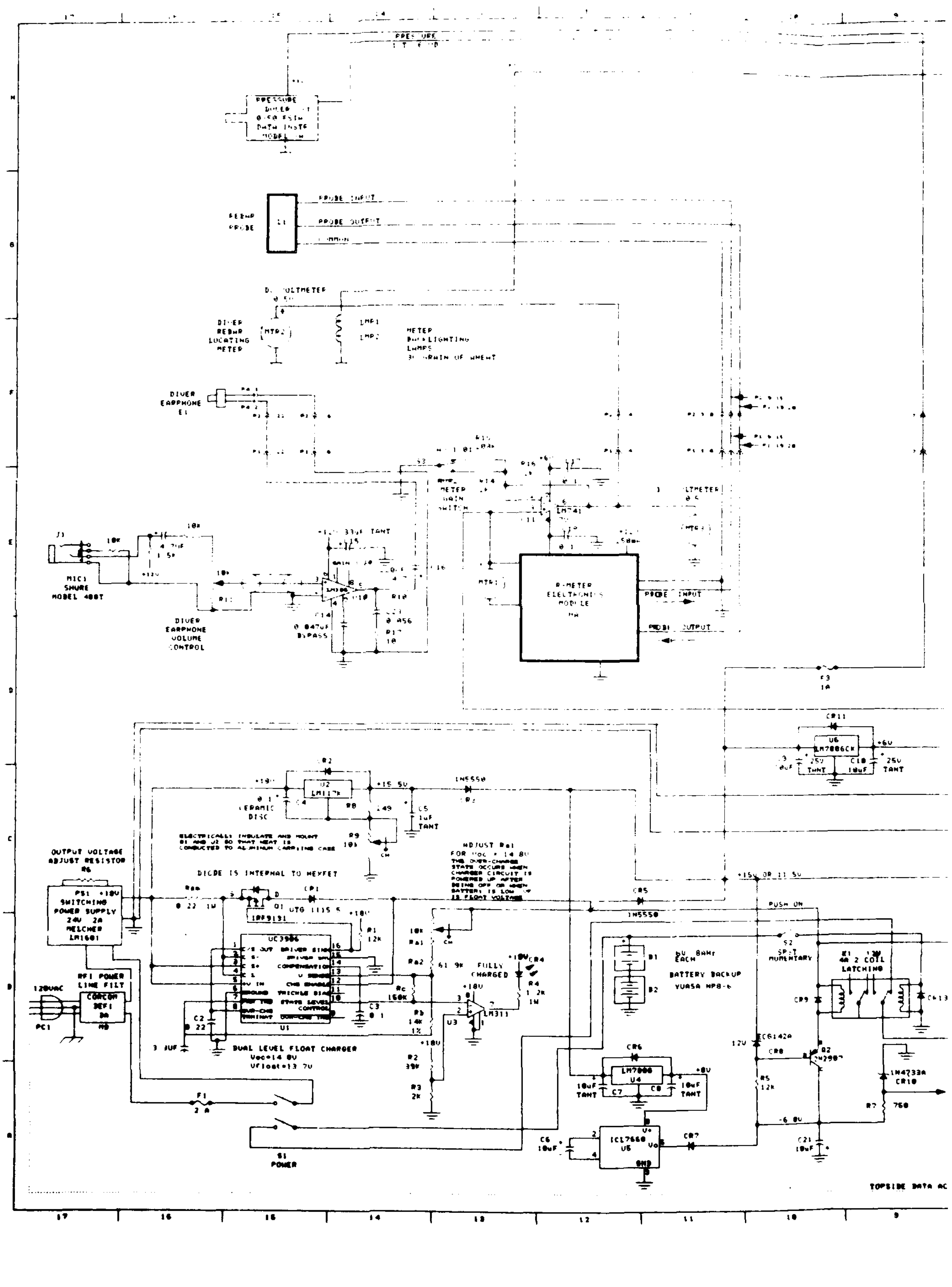
MECHANICAL DESIGN DRAWINGS
FOR
UMBILICAL CABLE



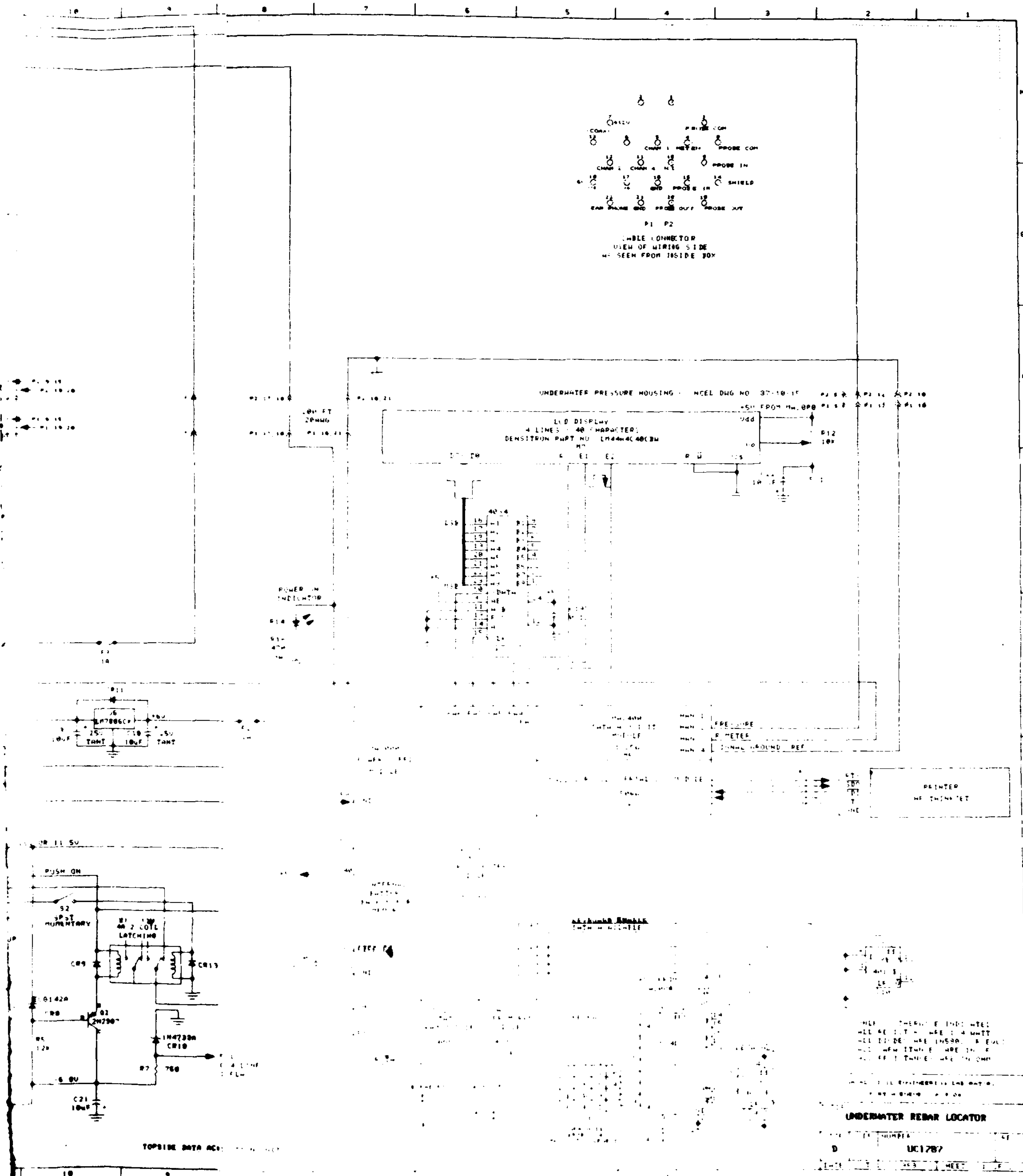

UNIVERSAL CABLE
COUPLER
TEE
DRY CONNECTOR
WET CONNECTOR
SPOOL ASSEMBLY
DRUM
SLOTTED END PLATE
END PLATE

Appendix C

ELECTRICAL DESIGN DRAWING
FOR
REBAR LOCATOR

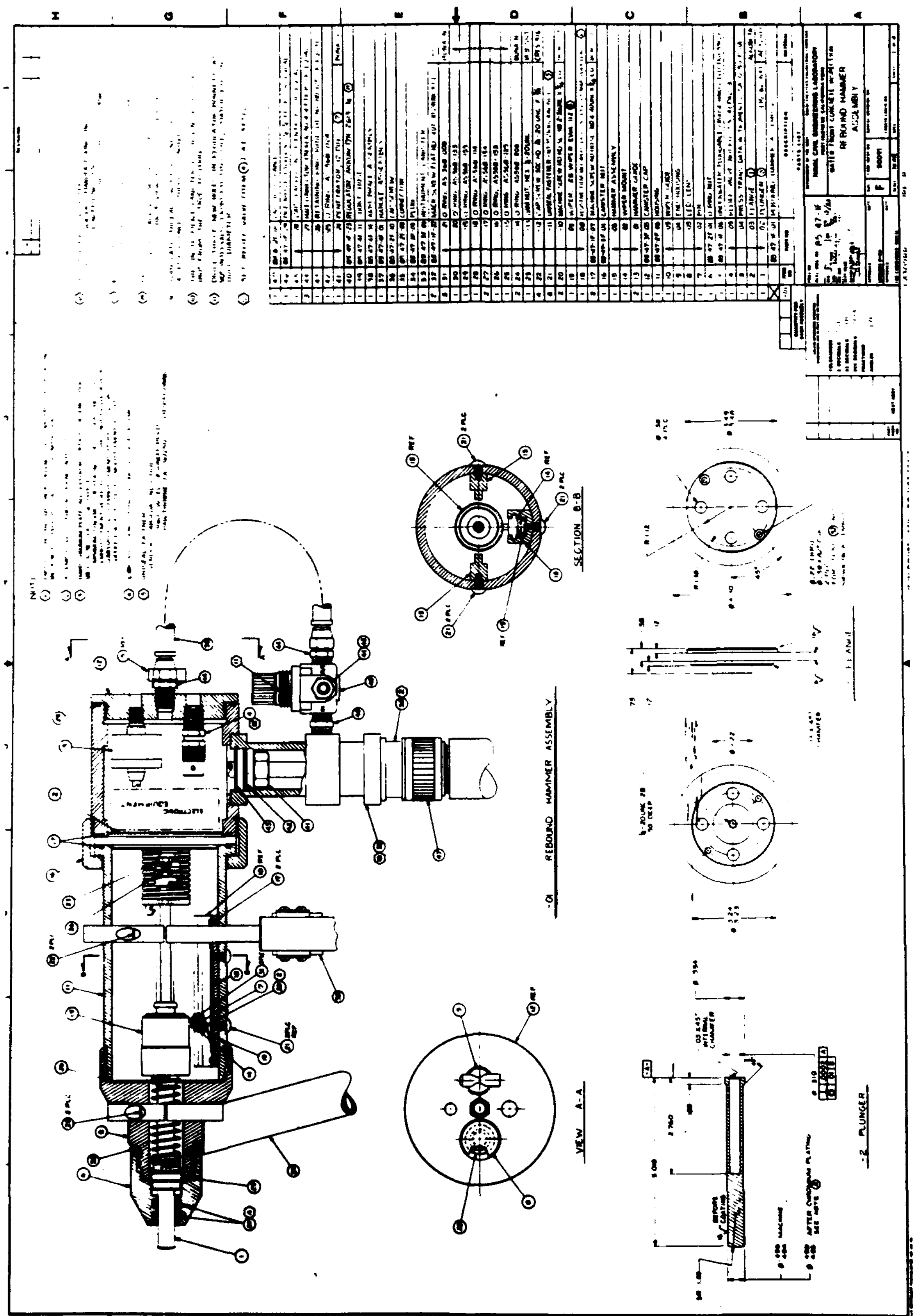


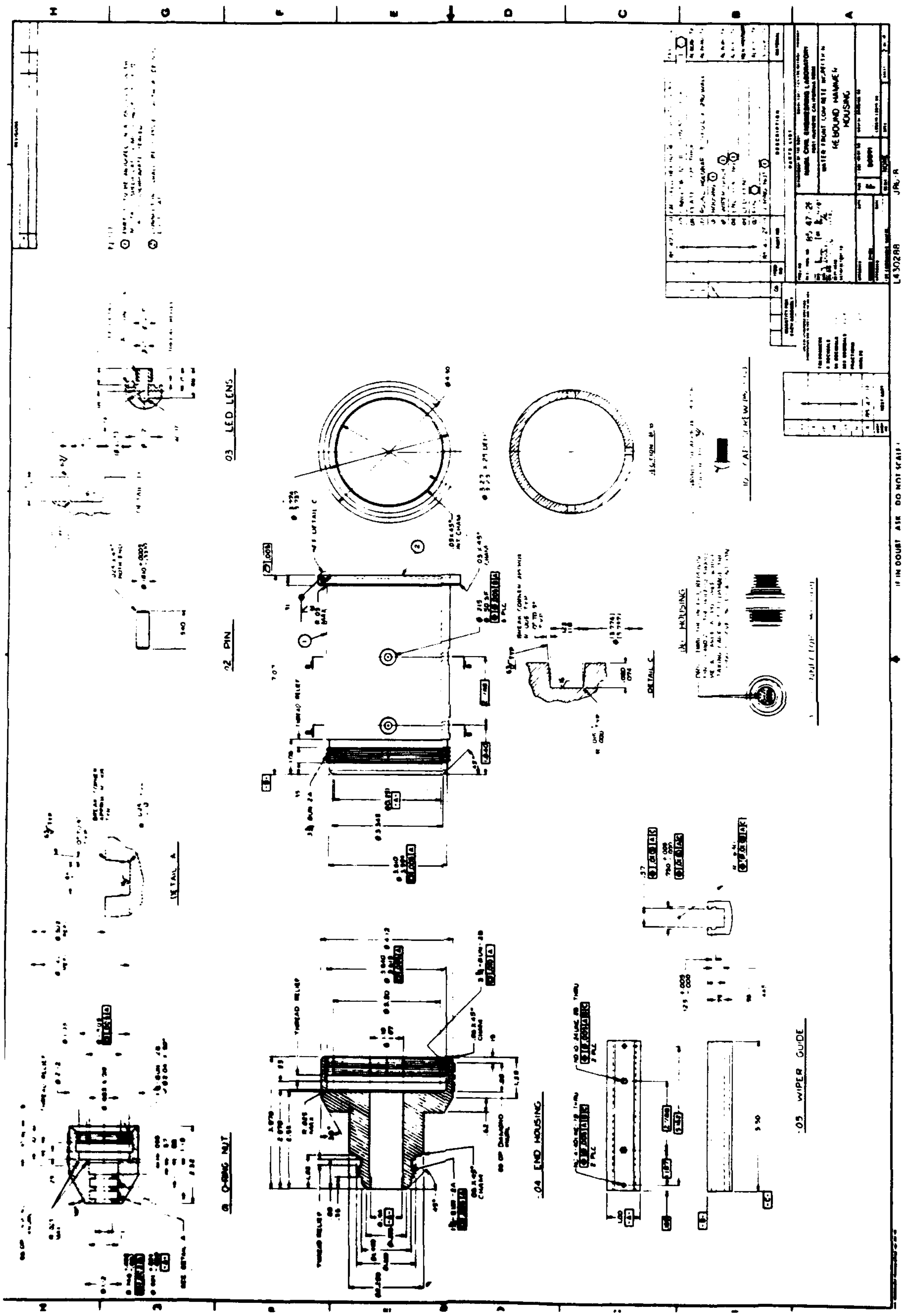
PROBE INPUT
PROBE OUTPUT
DIVER REBAR LOCATING METER
METER BACKLIGHTING LAMPS
DIVER EARPHONE
MIC1 SHURE MODEL 488T
DIVER EARPHONE VOLUME CONTROL
0.047uF BYPASS
R-METER ELECTRONICS MODULE
CR11
U6 LM7806CK
25V TANT
OUTPUT VOLTAGE ADJUST RESISTOR R6
CERAMIC DISC
1N5550
ELECTRICALLY INSULATE AND MOUNT Q1 AND U2 SO THAT HEAT IS CONDUCTED TO ALUMINUM CARRYING CASE
DIODE IS INTERNAL TO HEXFET
ADJUST Ra1
PS1 +18V SWITCHING POWER SUPPLY 24W 2A MELCHER LM1601
IRF9131
UC3906
FULLY CHARGED
6V 8AHr EACH
BATTERY BACKUP YUASA NP8-6
PUSH ON
S2 SPDT MOMENTARY
K1 12V 4A 2 COIL LATCHING
120VAC
RFI POWER LINE FILT CORCOM 3EF1 3A
PC1
DUAL LEVEL FLOAT CHARGER
LM311
LM7808
ICL7660
S1 POWER
1N4733A CR10
2N2907
TOPSIDE DATA AC


P1 P2
CABLE CONNECTOR
VIEW OF WIRING SIDE
AS SEEN FROM INSIDE BOX
UNDERWATER PRESSURE HOUSING
LCD DISPLAY
4 LINES X 40 CHARACTERS
POWER ON INDICATOR
PRESSURE
PRINTER
PUSH ON
S2
SPST
MOMENTARY
LATCHING
2N2907
UNDERWATER REBAR LOCATOR
UC1787
TOPSIDE DATA ACQ

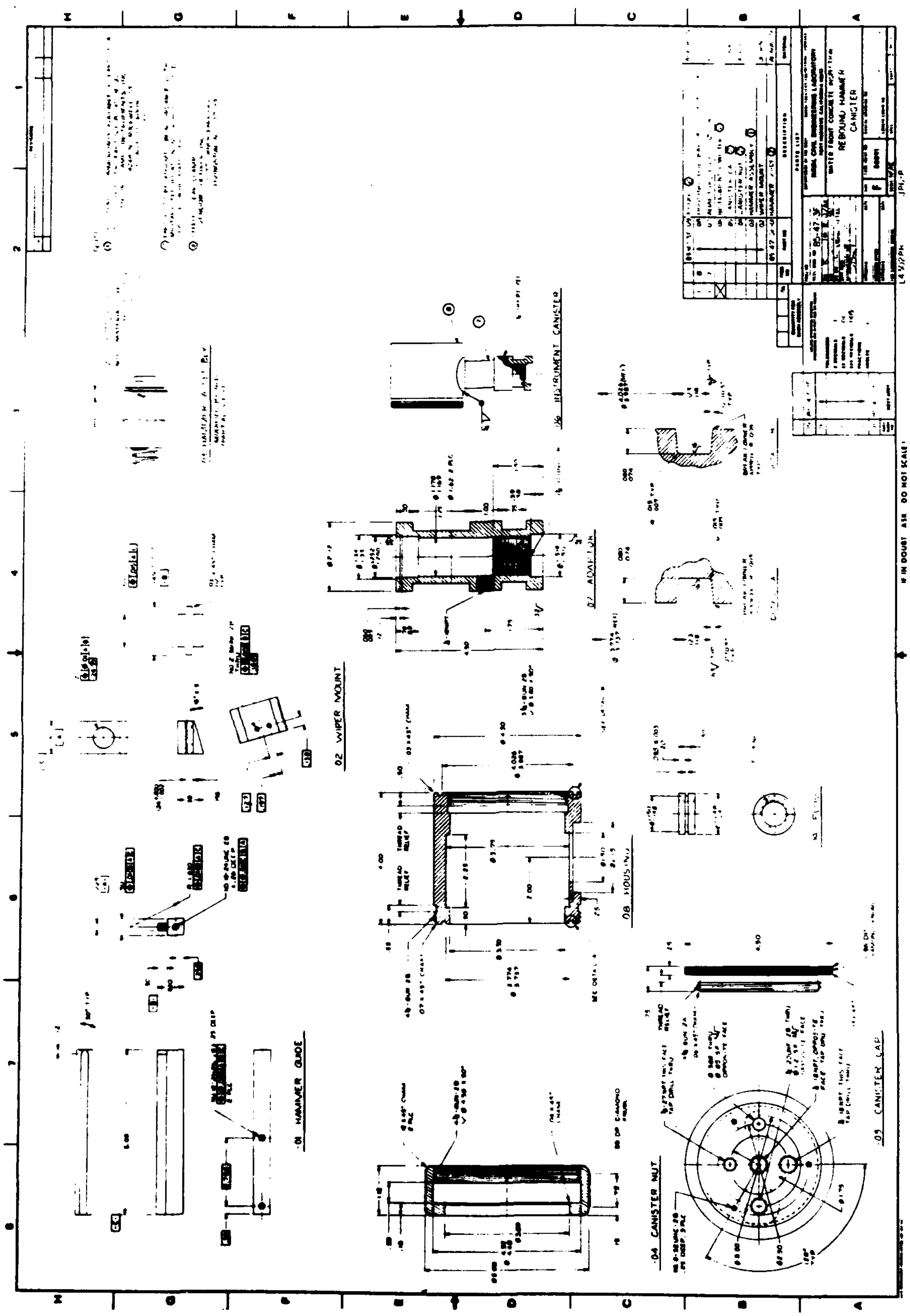
Appendix D

MECHANICAL DESIGN DRAWINGS FOR REBOUND HAMMER

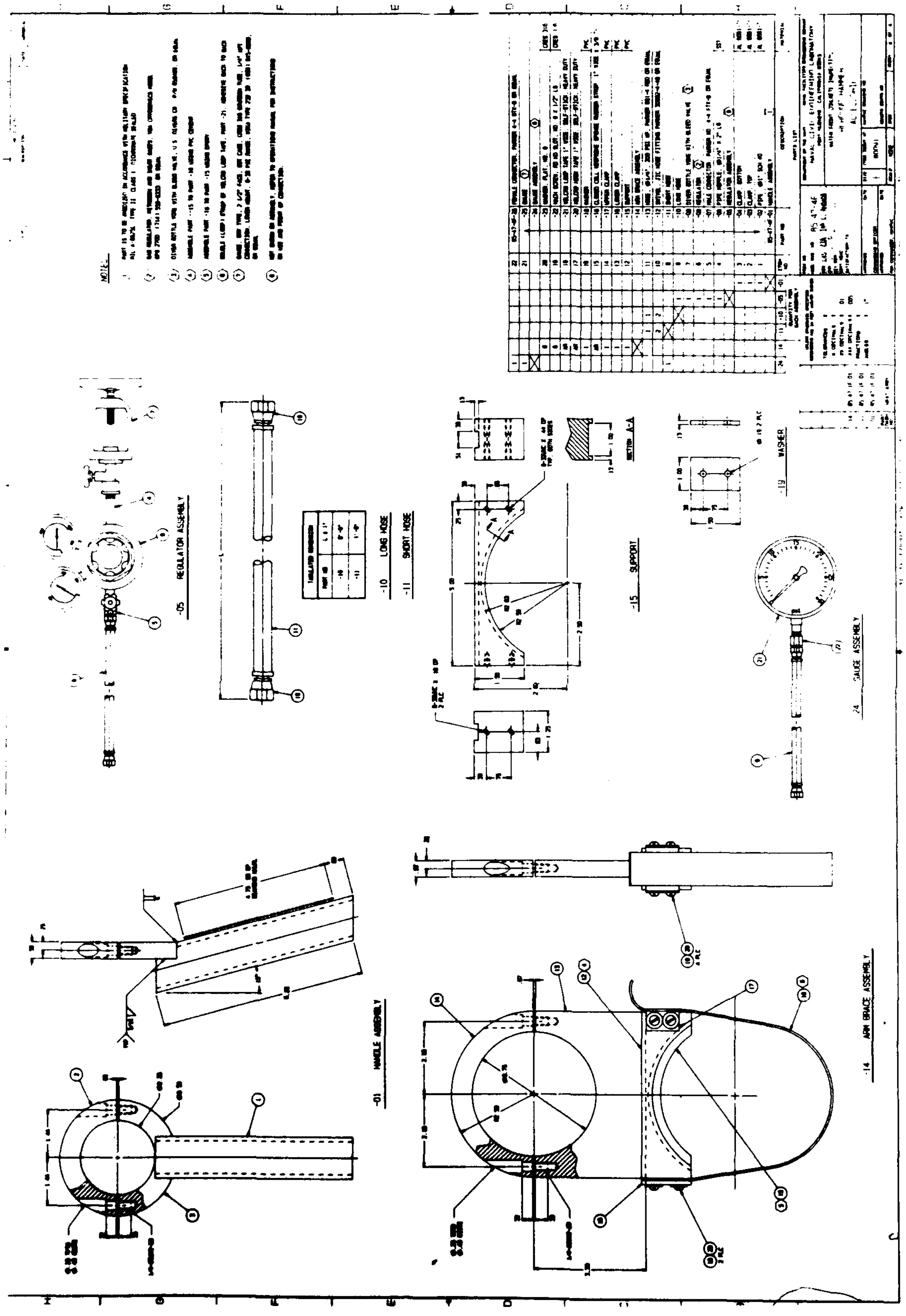

-01 REBOUND HAMMER ASSEMBLY
SECTION B-B
VIEW A-A
-2 PLUNGER
REBOUND HAMMER ASSEMBLY



01 O-RING NUT
02 PIN
03 LED LENS
.04 END HOUSING
.05 WIPER GUIDE
DETAIL A
DETAIL C
THREAD RELIEF
IF IN DOUBT ASK DO NOT SCALE
L4302RR



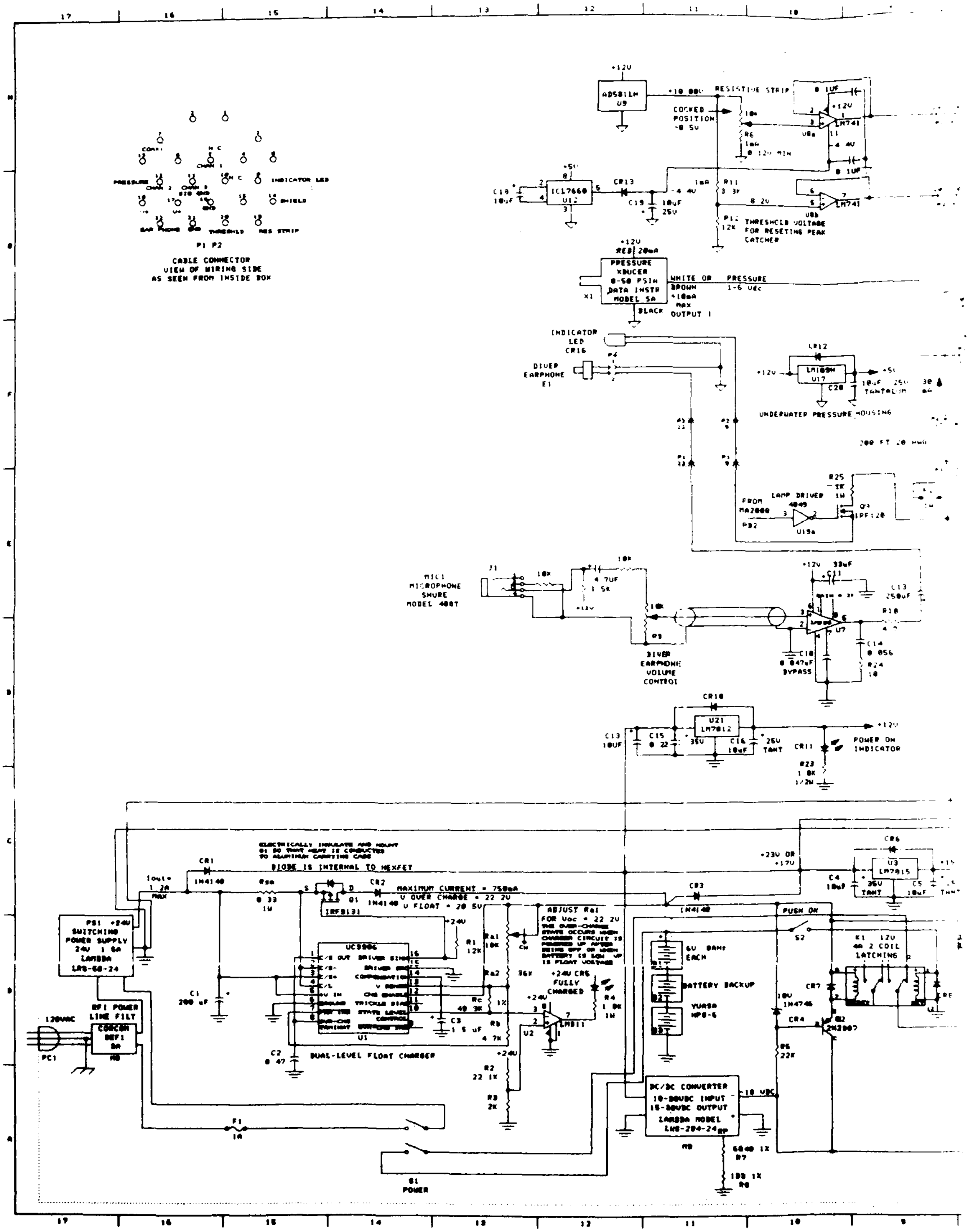
NAVAL CIVIL ENGINEERING LABORATORY
REBOUND HAMMER
CANISTER
PARTS LIST
DESCRIPTION
IF IN DOUBT ASK DO NOT SCALE
01 HAMMER GUIDE
02 WIPER MOUNT
08 HOUSING
04 CANISTER NUT
05 CANISTER CAP
06 INSTRUMENT CANISTER



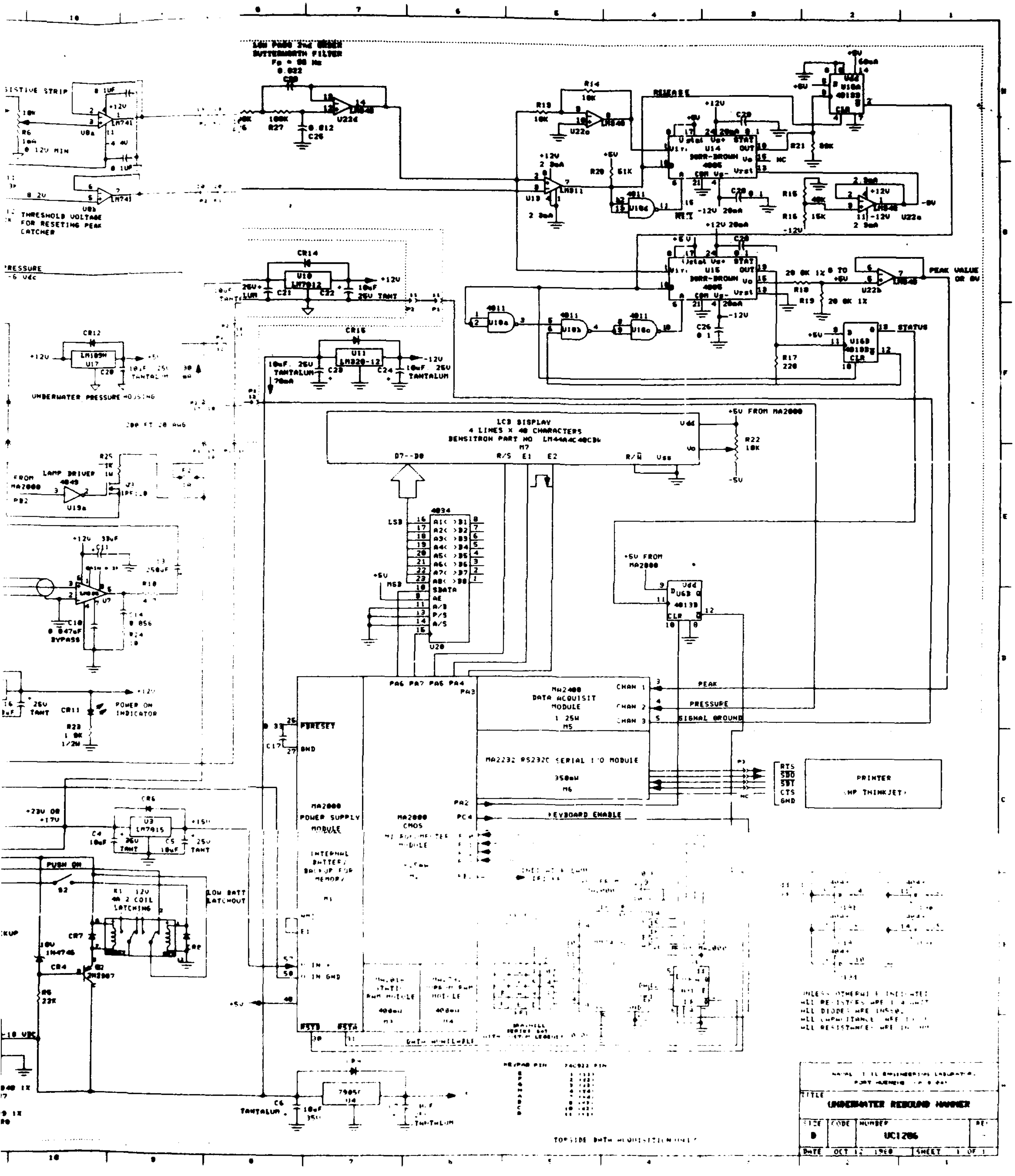
NOTES:
-05 REGULATOR ASSEMBLY
-10 LONG HOSE
-11 SHORT HOSE
-15 SUPPORT
SECTION A-A
-19 WASHER
-24 GAUGE ASSEMBLY
-01 HANDLE ASSEMBLY
-14 ARM BRACE ASSEMBLY

Appendix E

ELECTRICAL DESIGN DRAWING
FOR
REBOUND HAMMER

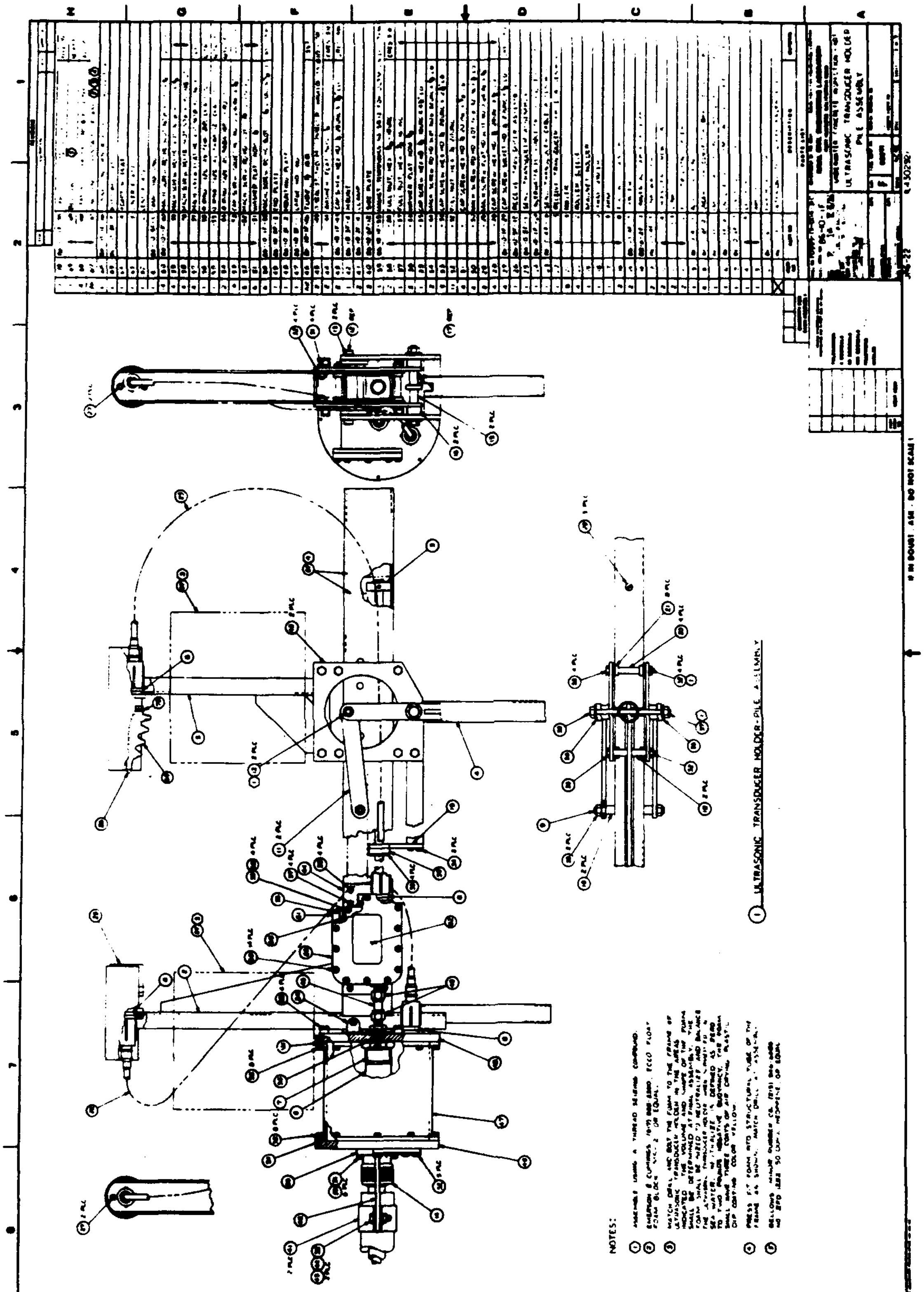


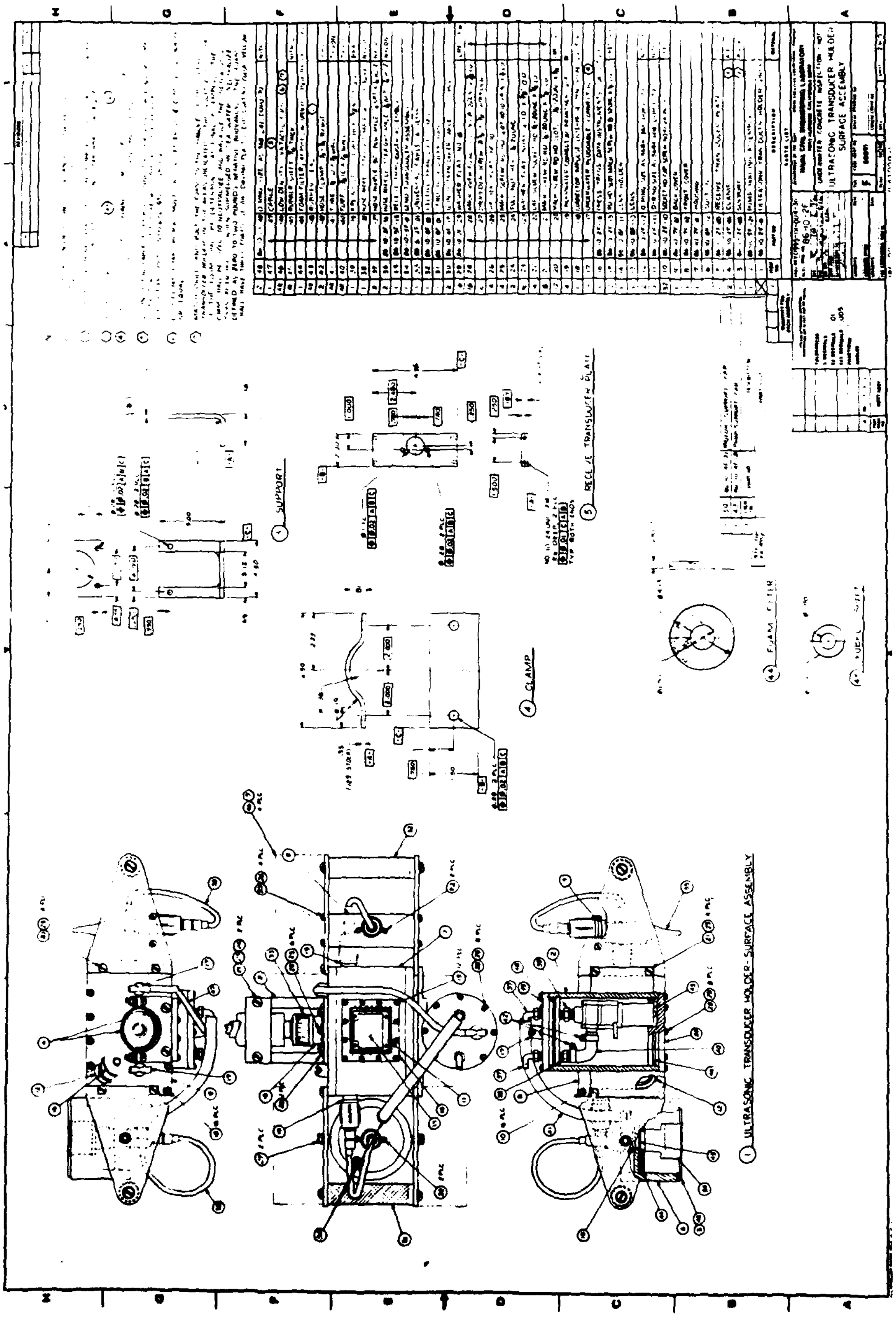
CABLE CONNECTOR
VIEW OF WIRING SIDE
AS SEEN FROM INSIDE BOX
P1 P2
PRESSURE
INDICATOR LED
SHIELD
EAR PHONE
THRESHOLD
RES STRIP
AD5811M
U9
RESISTIVE STRIP
COCKED POSITION
LM741
ICL7660
U12
THRESHOLD VOLTAGE FOR RESETING PEAK CATCHER
PRESSURE XDUCER 0-50 PSIA DATA INSTR MODEL SA
WHITE OR BROWN
PRESSURE 1-6 Vdc
BLACK
OUTPUT
INDICATOR LED CR16
DIVER EARPHONE E1
LM109H
U17
TANTALUM
UNDERWATER PRESSURE HOUSING
LAMP DRIVER
FROM MA2000
IRF120
MIC1 MICROPHONE SHURE MODEL 408T
DIVER EARPHONE VOLUME CONTROL
BYPASS
U21
LM7812
POWER ON INDICATOR
ELECTRICALLY INSULATE AND MOUNT Q1 SO THAT HEAT IS CONDUCTED TO ALUMINUM CARRYING CASE
DIODE IS INTERNAL TO HEXFET
MAXIMUM CURRENT = 750mA
V OVER CHARGE = 22 2V
V FLOAT = 20 5V
ADJUST Ra1
FOR Voc = 22 2V
FULLY CHARGED
UC3906
U1
DUAL-LEVEL FLOAT CHARGER
PS1 +24V SWITCHING POWER SUPPLY 24V 1 6A LAMBDA LRS-60-24
RFI POWER LINE FILT CORCOM 6EF1 3A
120VAC
PC1
F1 1A
S1 POWER
LM311
U2
6V 8AHr EACH
BATTERY BACKUP
YUASA NP8-6
DC/DC CONVERTER 10-80VDC INPUT 15-80VDC OUTPUT LAMBDA MODEL LMS-204-24
PUSH ON
S2
K1 12V 4A 2 COIL LATCHING
2N2907
U3
LM7915


LOW PASS 2nd ORDER BUTTERWORTH FILTER
LCD DISPLAY
4 LINES X 40 CHARACTERS
DENSITRON PART NO LM44A4C40CBW
MA2400 DATA ACQUISIT MODULE
MA2232 RS232C SERIAL I/O MODULE
MA2000 POWER SUPPLY MODULE
MA2000 CMOS
PRINTER
(HP THINKJET)
PEAK
PRESSURE
SIGNAL GROUND
KEYBOARD ENABLE
PEAK VALUE
STATUS
RELEASE
THRESHOLD VOLTAGE FOR RESETING PEAK CATCHER
UNDERWATER PRESSURE HOUSING
LAMP DRIVER
POWER ON INDICATOR
PUSH ON
LOW BATT LATCHOUT
UNDERWATER REBOUND HAMMER
UC1286
TOPSIDE DATA ACQUISITION UNIT

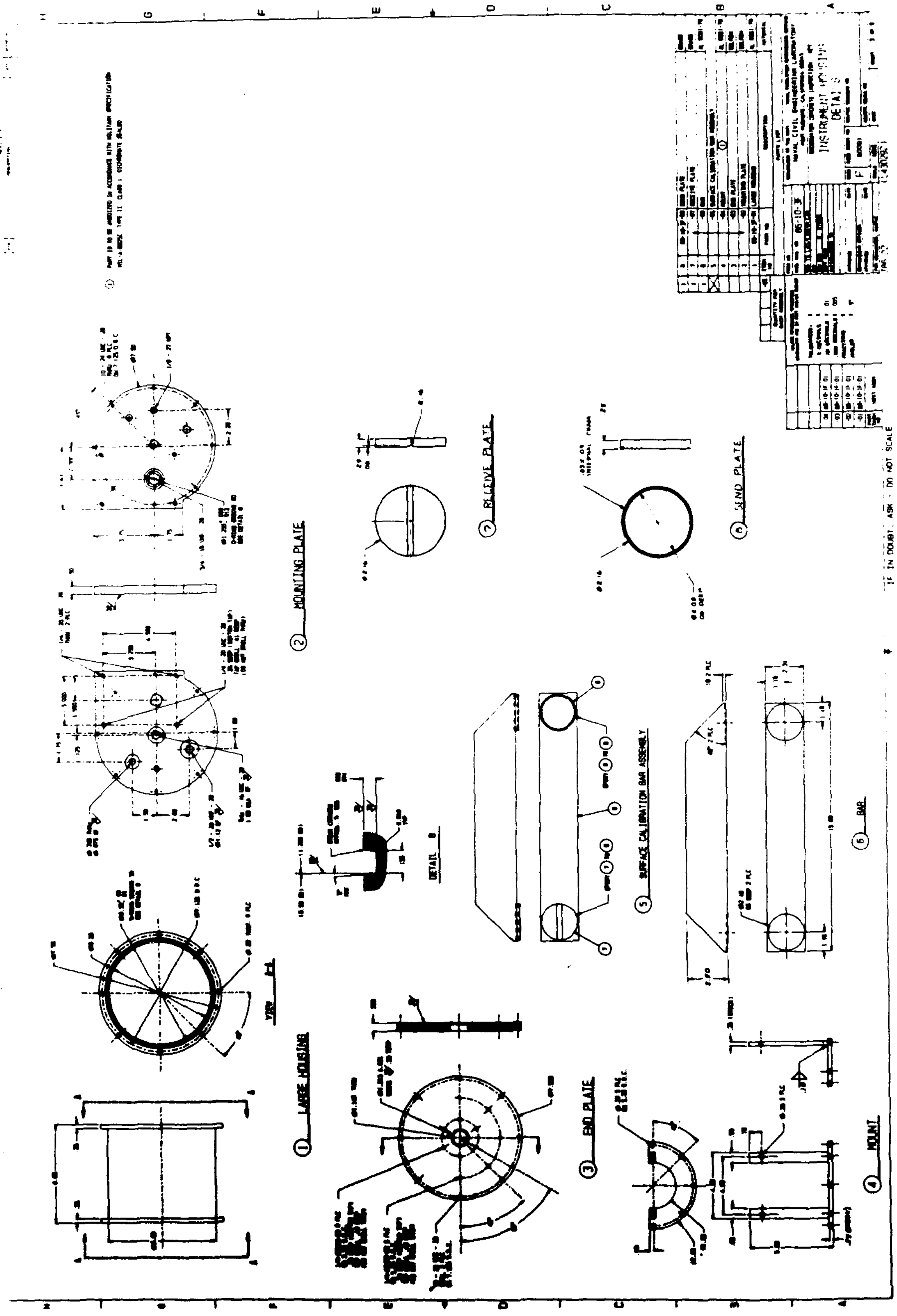
Appendix F

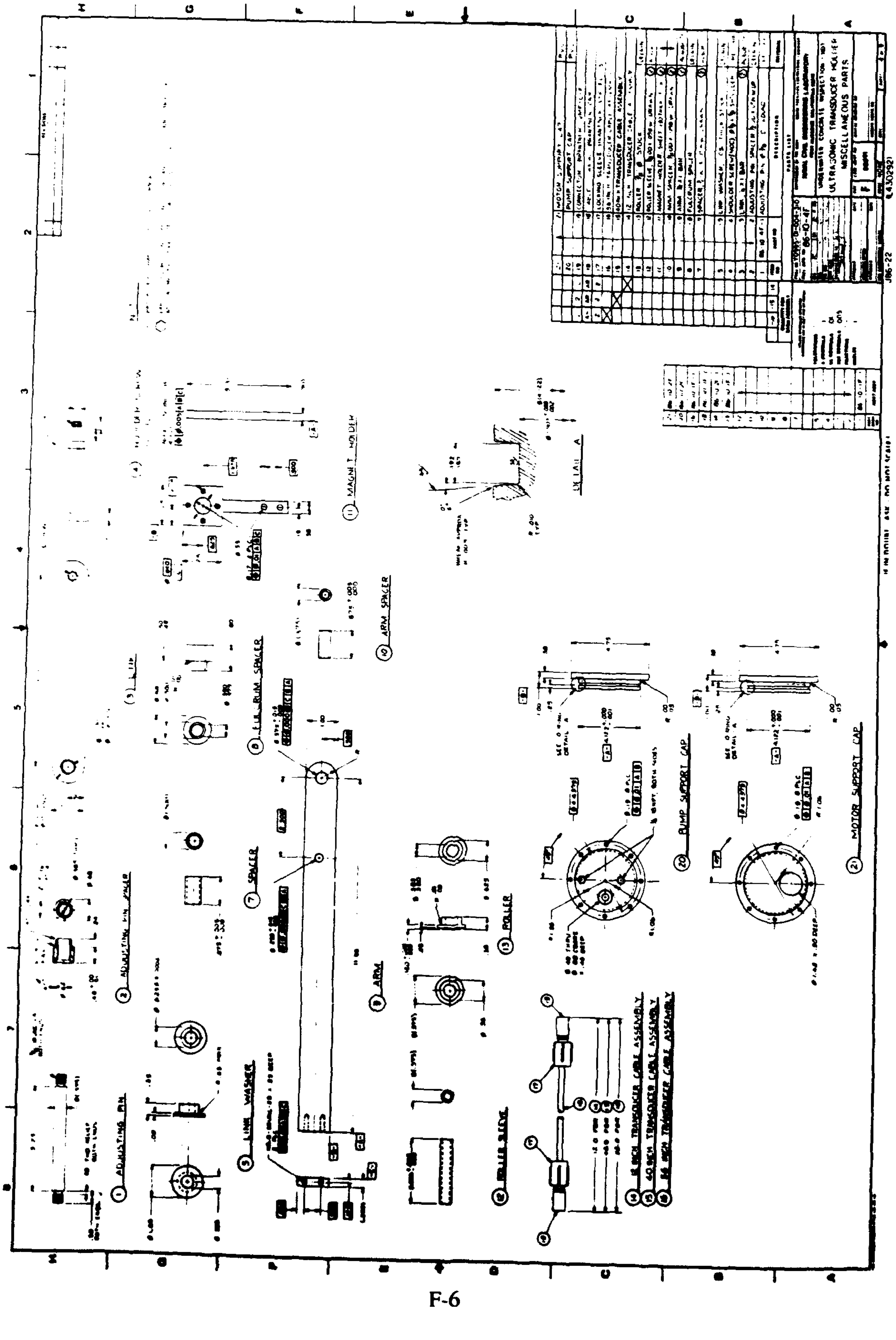
MECHANICAL DESIGN DRAWINGS
FOR
ULTRASONIC TEST SYSTEM

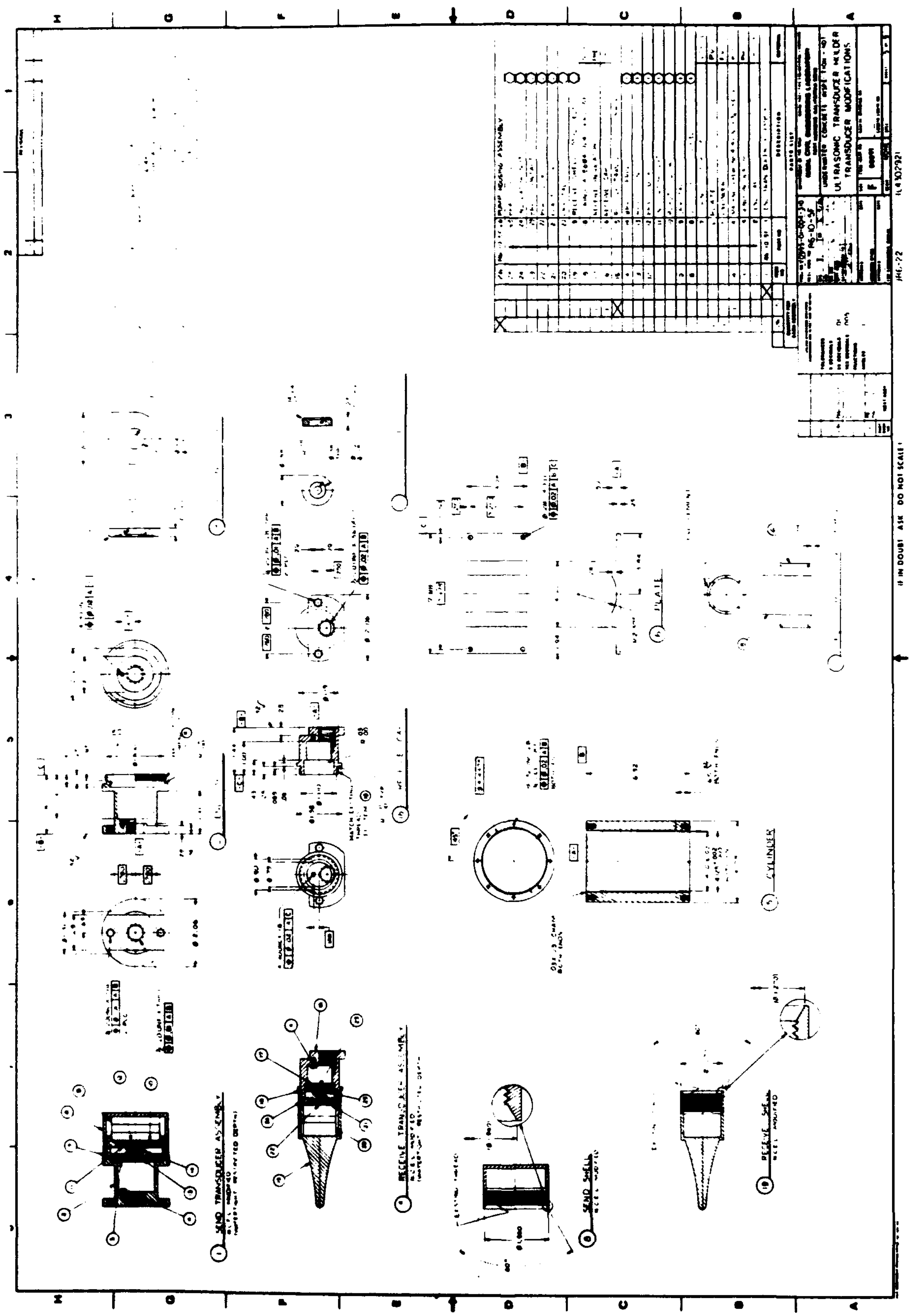

ULTRASONIC TRANSDUCER HOLDER-PILE ASSEMBLY
NOTES:

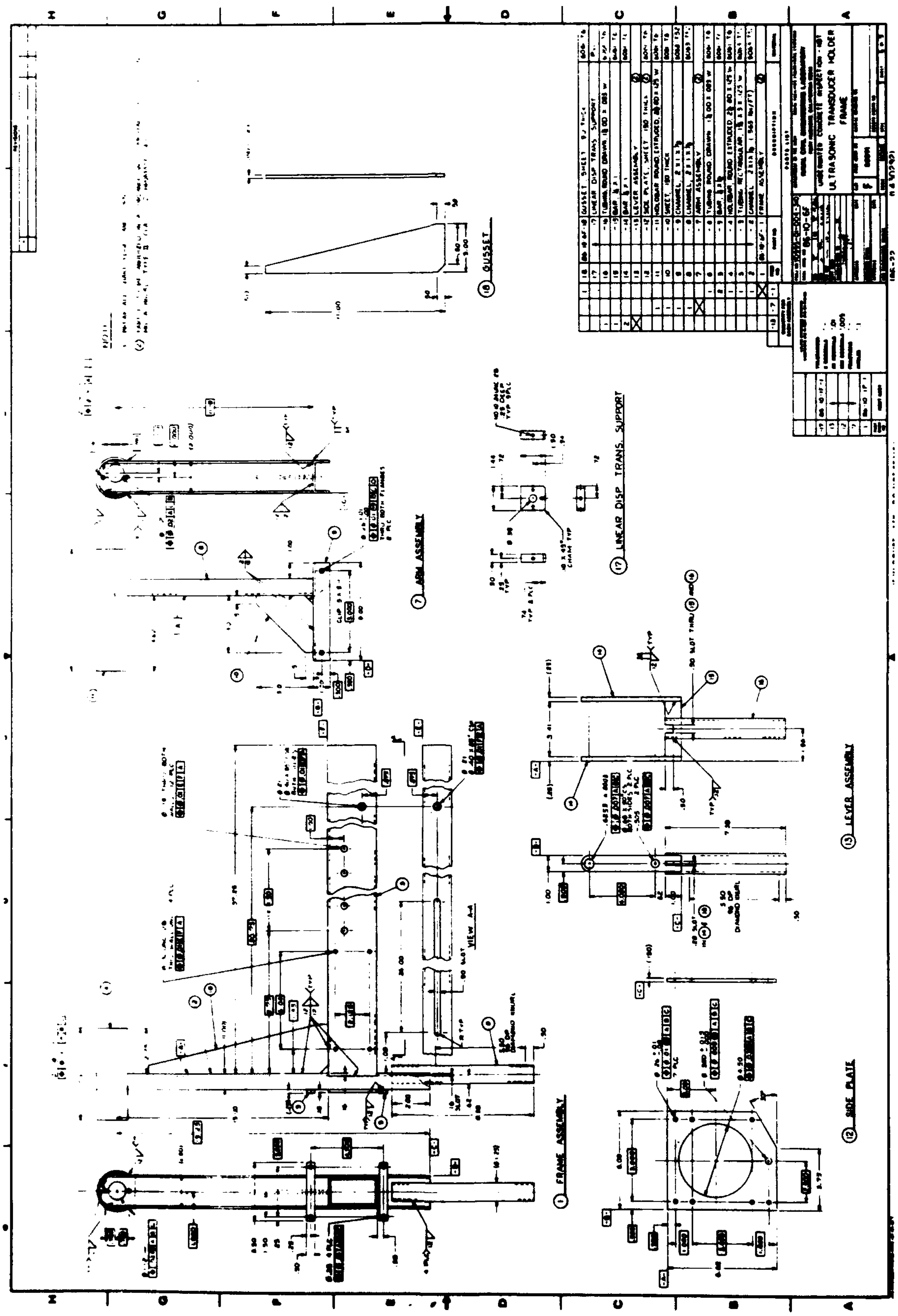


ULTRASONIC TRANSDUCER HOLDER-SURFACE ASSEMBLY
SUPPORT
CLAMP
RECEIVE TRANSDUCER PLATE
ULTRASONIC TRANSDUCER HOLDER SURFACE ASSEMBLY

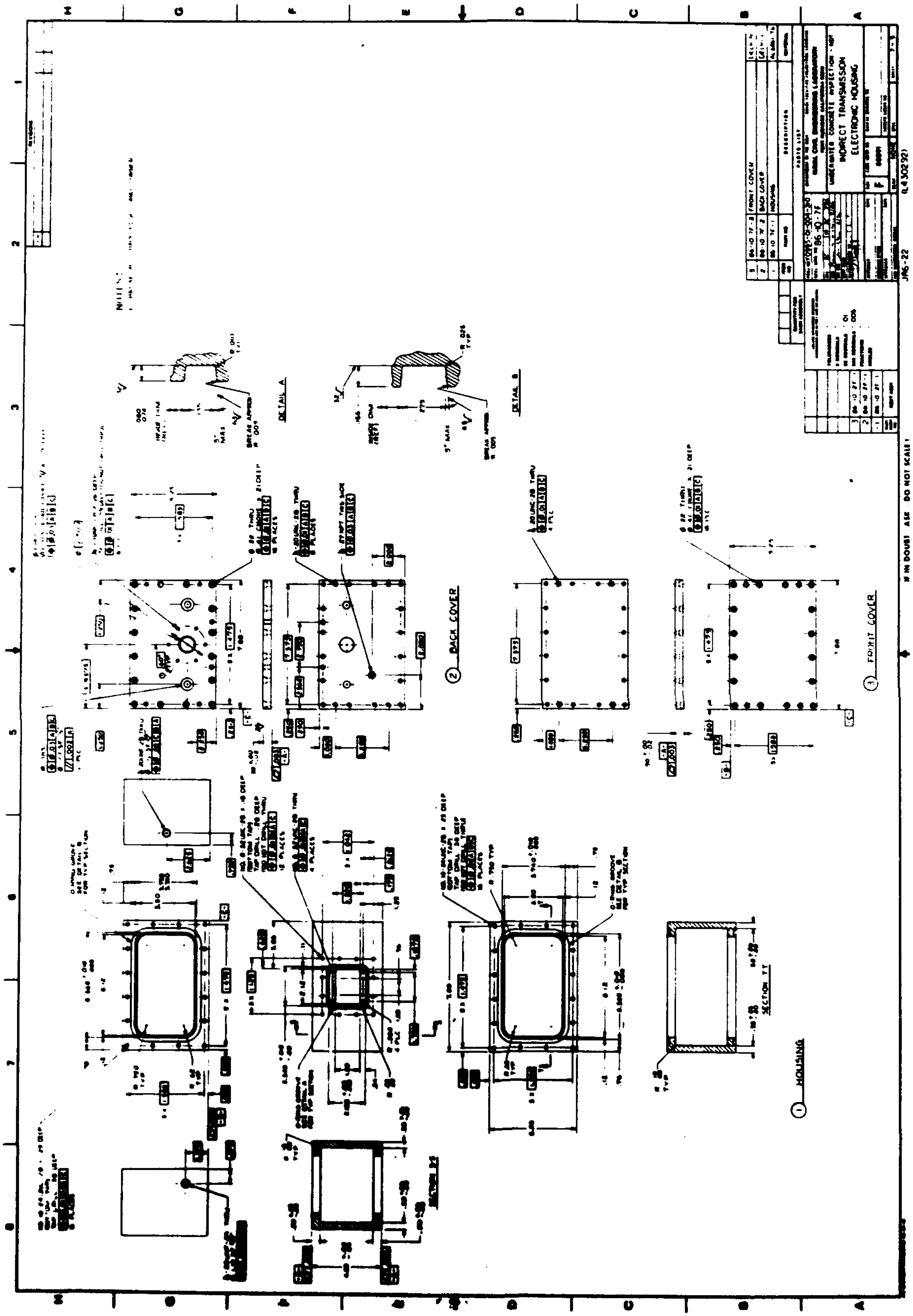

INSTRUMENT HOUSING DETAILS
LARGE HOUSING
MOUNTING PLATE
END PLATE
MOUNT
SURFACE CALIBRATION BAR ASSEMBLY
BAR
RECEIVE PLATE
SEND PLATE
DETAIL B
IF IN DOUBT ASK - DO NOT SCALE

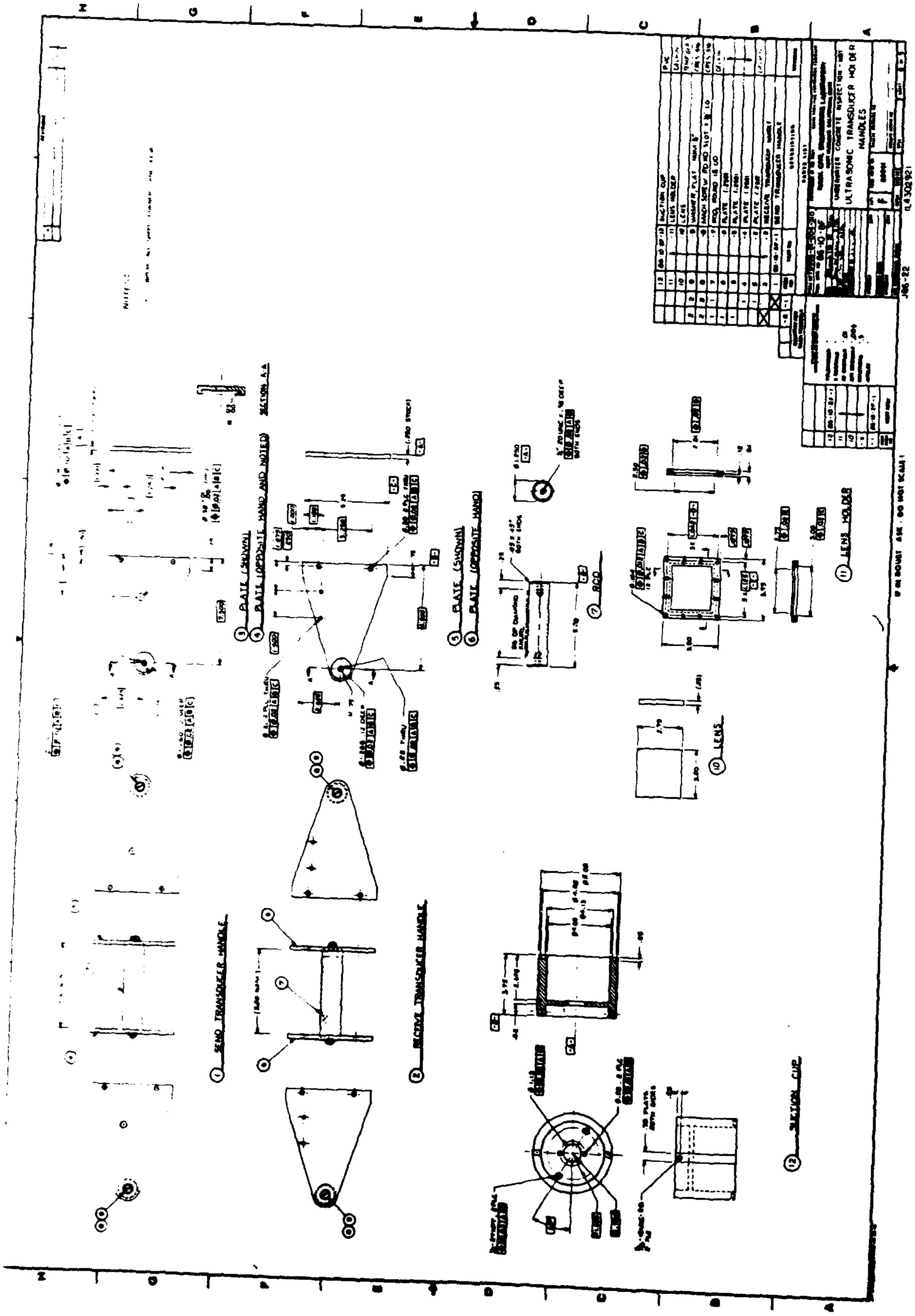

ADJUSTING PIN
ADJUSTING PIN SPACER
LINK WASHER
ARM
ROLLER SLEEVE
ROLLER
SPACER
MAGNET HOLDER
ARM SPACER
DETAIL A
PUMP SUPPORT CAP
MOTOR SUPPORT CAP
12 INCH TRANSDUCER CABLE ASSEMBLY
40 INCH TRANSDUCER CABLE ASSEMBLY
ULTRASONIC TRANSDUCER HOLDER
MISCELLANEOUS PARTS


ULTRASONIC TRANSDUCER HOLDER
TRANSDUCER MODIFICATIONS
SEND TRANSDUCER ASSEMBLY
RECEIVE TRANSDUCER ASSEMBLY
SEND SHELL
RECEIVE SHELL
CYLINDER
PLATE
IF IN DOUBT ASK DO NOT SCALE!

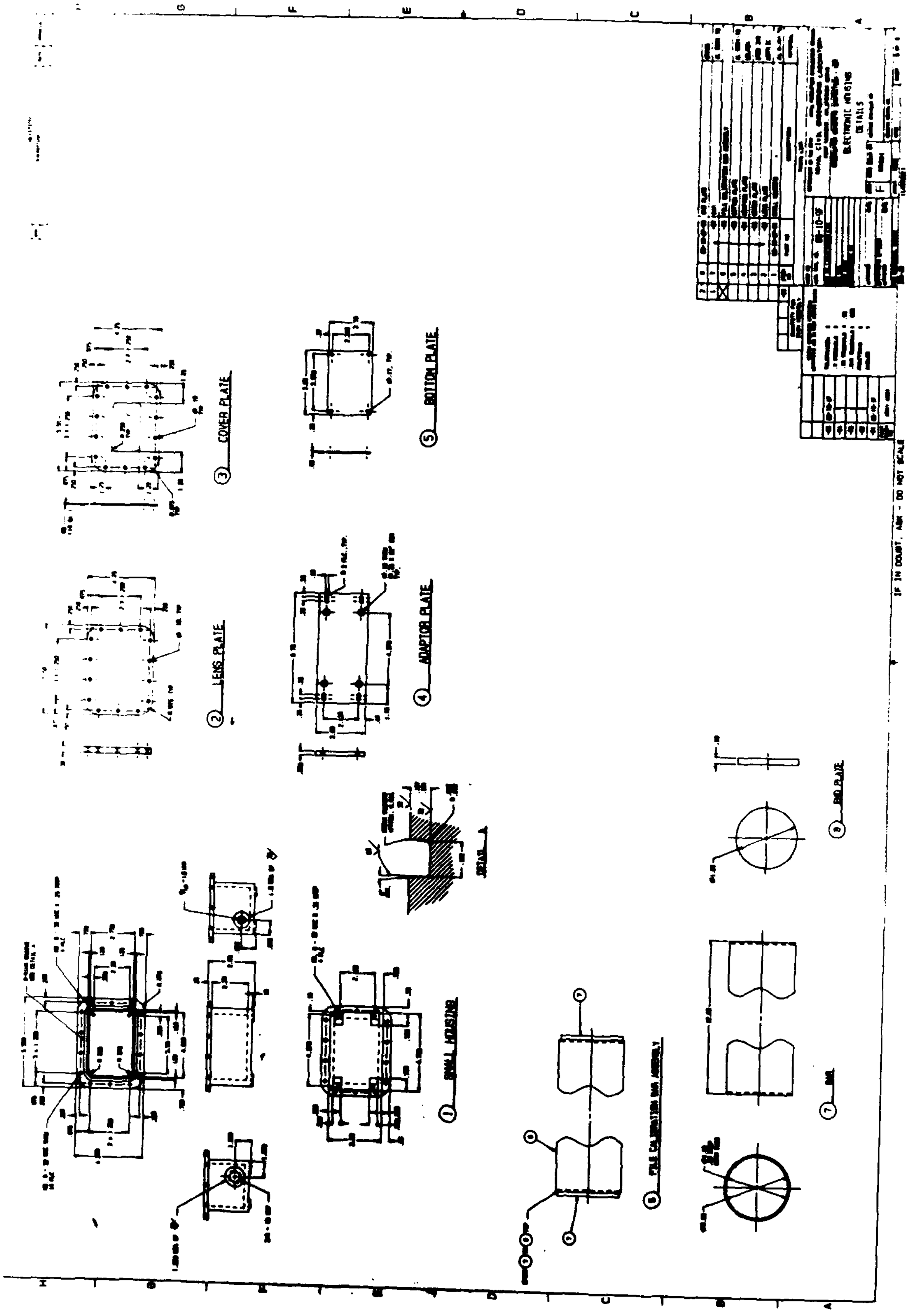


FRAME ASSEMBLY
SIDE PLATE
LEVER ASSEMBLY
ARM ASSEMBLY
LINEAR DISP TRANS SUPPORT
GUSSET
VIEW A-A
ULTRASONIC TRANSDUCER HOLDER FRAME


BACK COVER
FRONT COVER
HOUSING
DETAIL A
DETAIL B
ELECTRONIC HOUSING



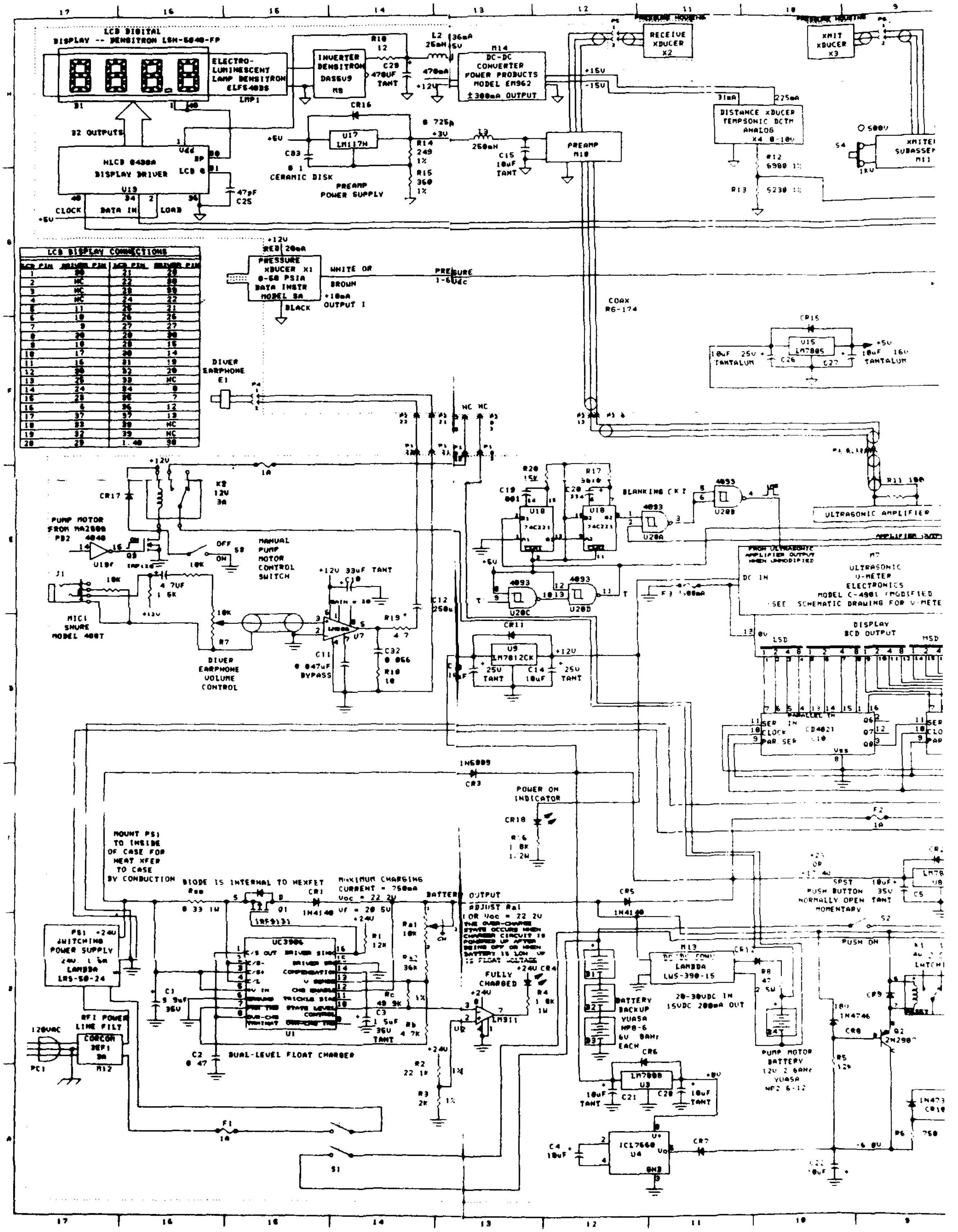
SEND TRANSDUCER HANDLE
RECEIVE TRANSDUCER HANDLE
PLATE (SHOWN)
PLATE (OPPOSITE HAND)
SECTION A-A
ROD
LENS
LENS HOLDER
SUCTION CUP
UNDERWATER CONCRETE INSPECTION UNIT
ULTRASONIC TRANSDUCER HOLDER HANDLES
IF IN DOUBT ASK - DO NOT SCALE!



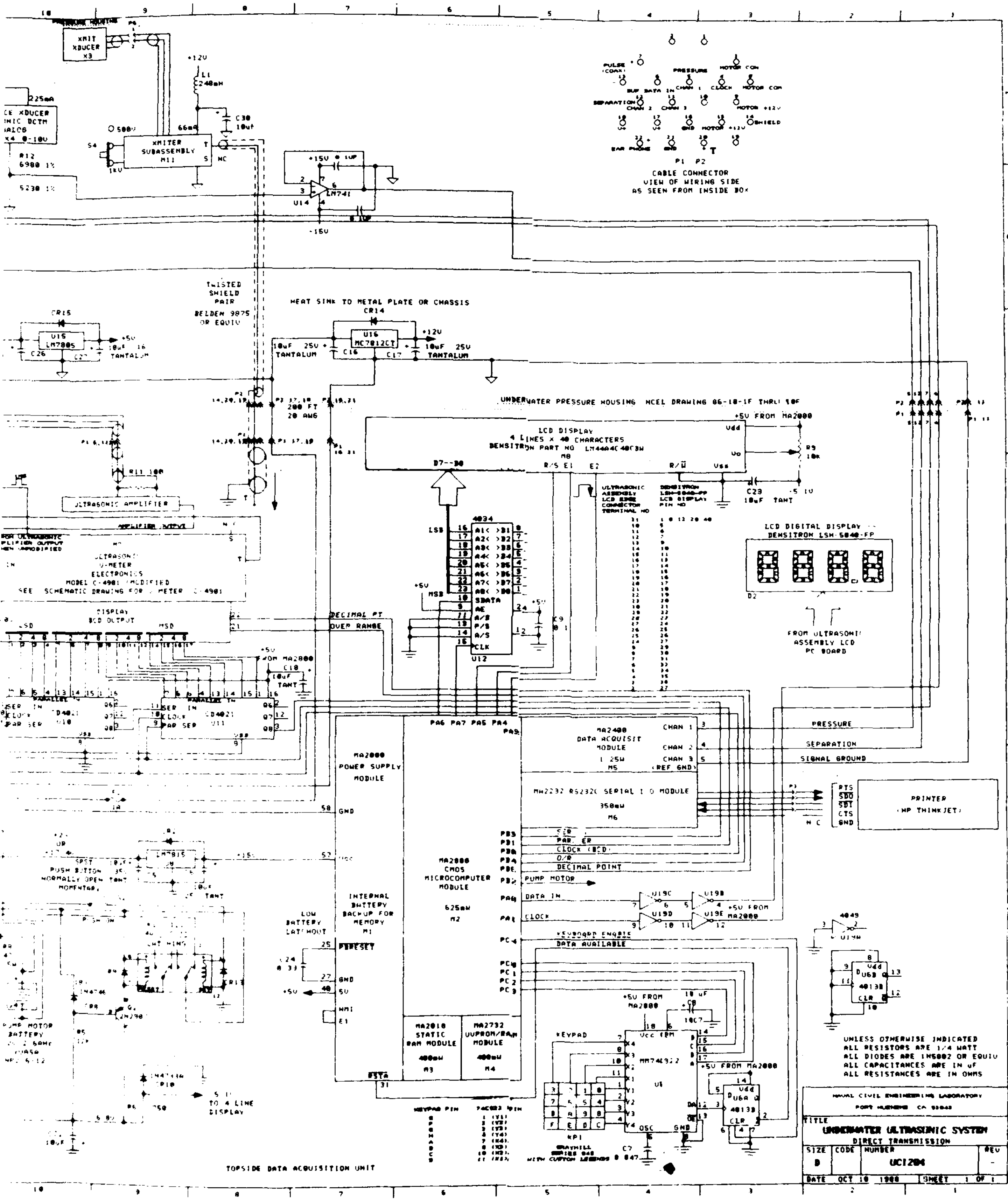
1 SMALL HOUSING
2 LENS PLATE
3 COVER PLATE
4 ADAPTOR PLATE
5 BOTTOM PLATE
6 POLE CALIBRATION BAR ASSEMBLY
7 BAR
8 END PLATE
DETAIL A
IF IN DOUBT, ASK - DO NOT SCALE
ELECTRONIC HOUSING
DETAILS

Appendix G

ELECTRICAL DESIGN DRAWING
FOR
ULTRASONIC TEST SYSTEM
DIRECT MEASUREMENTS



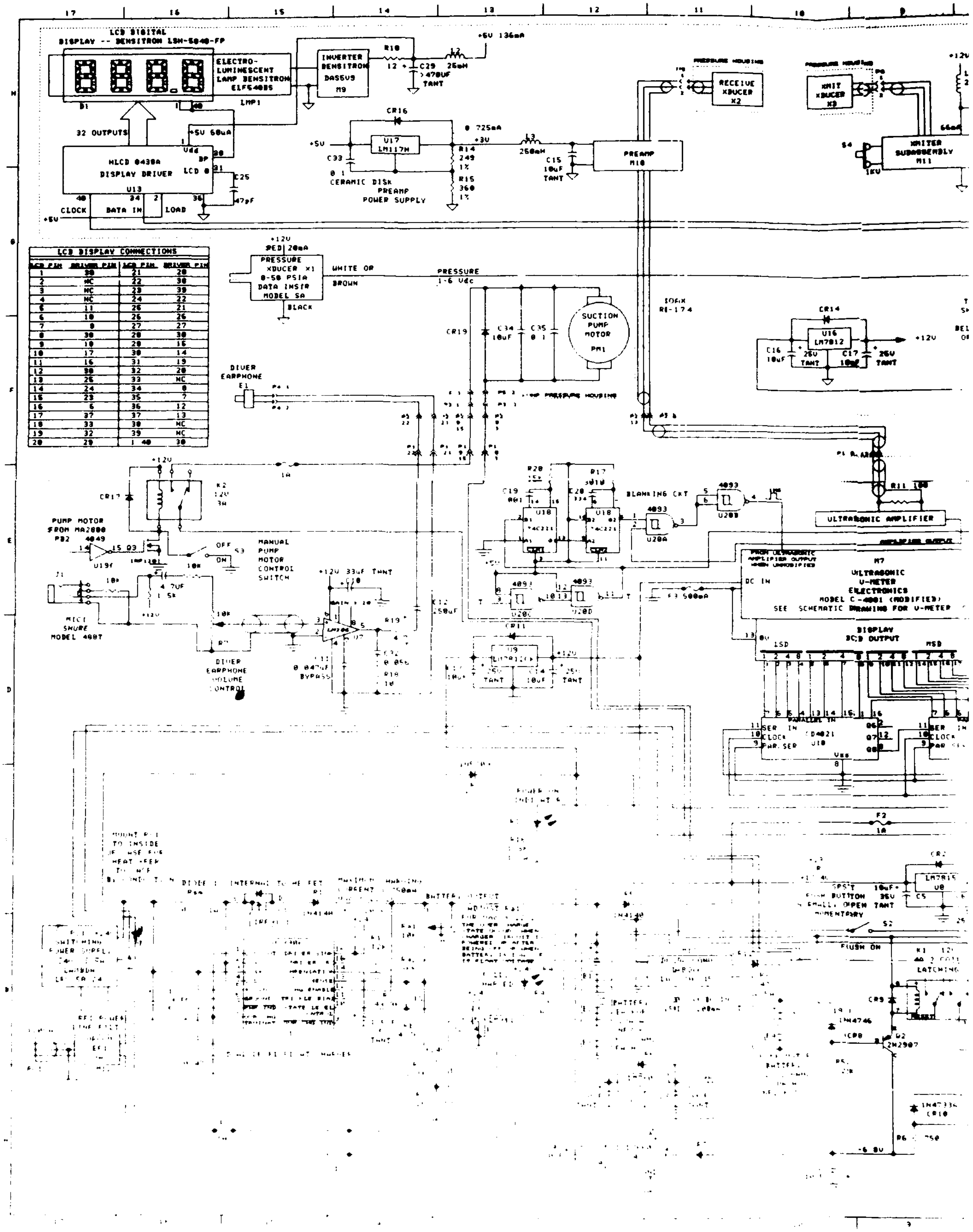
LCD DISPLAY CONNECTIONS			
LCD PIN	DRIVER PIN	LCD PIN	DRIVER PIN
1	30	21	20
2	NC	22	30
3	NC	23	39
4	NC	24	22
5	11	25	21
6	10	26	26
7	9	27	27
8	20	28	30
9	18	29	15
10	17	30	14
11	16	31	19
12	30	32	20
13	25	33	NC
14	24	34	8
15	23	35	7
16	6	36	12
17	37	37	13
18	33	38	NC
19	32	39	NC
20	29	1, 40	30



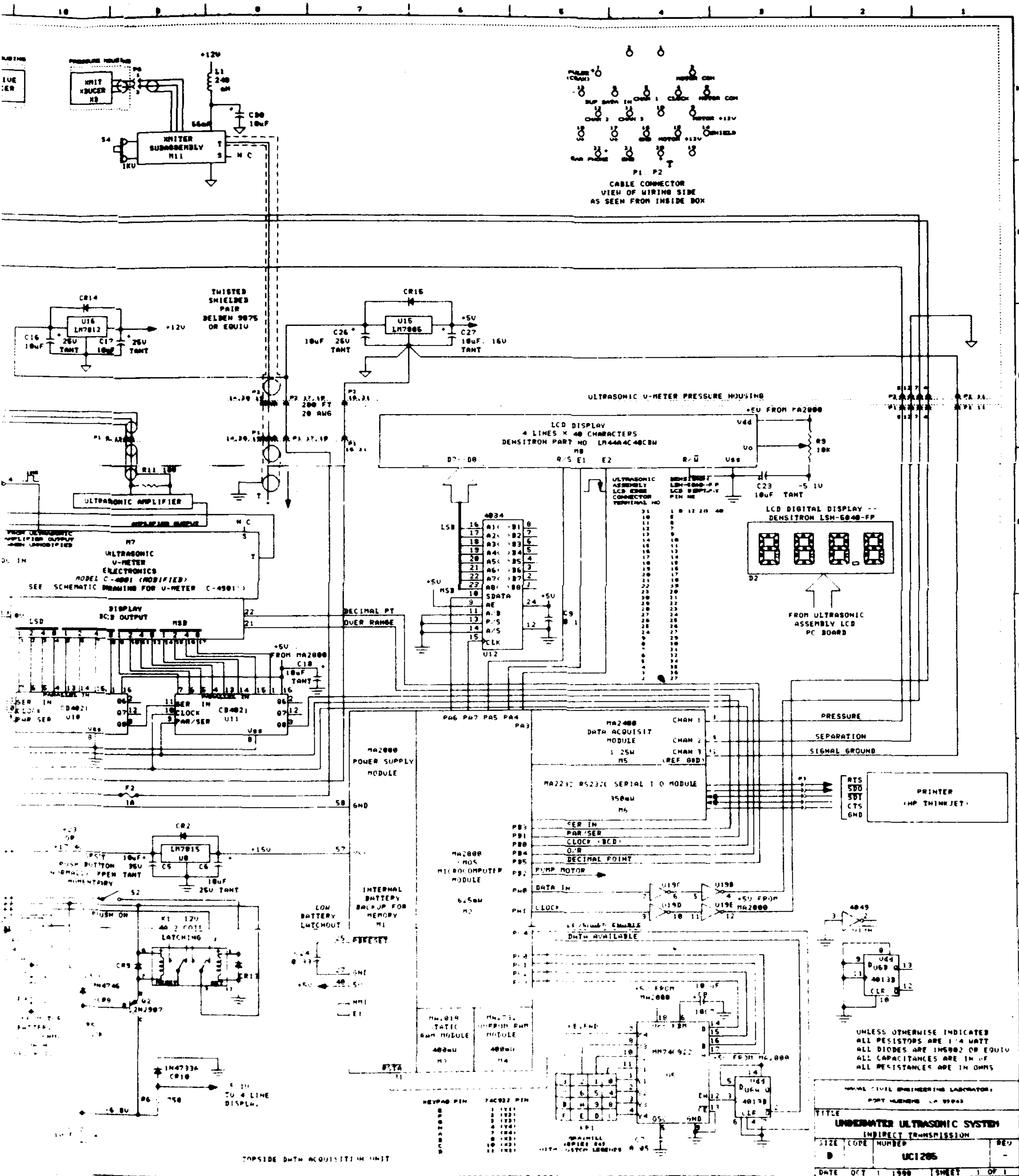
XMIT XDUCER X3
XMITER SUBASSEMBLY M11
LM741
CABLE CONNECTOR
VIEW OF WIRING SIDE
AS SEEN FROM INSIDE BOX
P1 P2
TWISTED SHIELD PAIR
BELDEN 9875 OR EQUIV
HEAT SINK TO METAL PLATE OR CHASSIS
LM7805
MC7812CT
TANTALUM
UNDERWATER PRESSURE HOUSING NCEL DRAWING 86-10-1F THRU 10F
+5V FROM MA2000
LCD DISPLAY
4 LINES x 40 CHARACTERS
DENSITRON PART NO LM44A4C40CBW
M8
ULTRASONIC AMPLIFIER
ULTRASONIC U-METER ELECTRONICS
MODEL C-4901 (MODIFIED)
SEE SCHEMATIC DRAWING FOR U-METER C-4901
DISPLAY BCD OUTPUT
4034
U12
DECIMAL PT
OVER RANGE
LCD DIGITAL DISPLAY -- DENSITRON LSH-5040-FP
FROM ULTRASONIC ASSEMBLY LCD PC BOARD
CD4021
MA2000 POWER SUPPLY MODULE
MA2400 DATA ACQUISIT MODULE
M5
CHAN 1
CHAN 2
CHAN 3
PRESSURE
SEPARATION
SIGNAL GROUND
MA2232 RS232C SERIAL I O MODULE
350mW
M6
PRINTER (HP THINKJET)
RTS
SDO
SDI
CTS
GND
MA2000 CMOS MICROCOMPUTER MODULE
625mW
M2
INTERNAL BATTERY BACKUP FOR MEMORY
M1
LOW BATTERY LATCHOUT
PUMP MOTOR
DATA IN
CLOCK
DECIMAL POINT
KEYBOARD ENABLE
DATA AVAILABLE
MA2010 STATIC RAM MODULE
M3
MA2732 UVPROM/RAM MODULE
M4
KEYPAD
MM74C922
U1
4049
40138
KP1
GRAYHILL
WITH CUSTOM LEGENDS
TO 4 LINE DISPLAY
PUMP MOTOR BATTERY
UNLESS OTHERWISE INDICATED
ALL RESISTORS ARE 1/4 WATT
ALL DIODES ARE 1N5002 OR EQUIV
ALL CAPACITANCES ARE IN uF
ALL RESISTANCES ARE IN OHMS
NAVAL CIVIL ENGINEERING LABORATORY
PORT HUENEME CA 93043
TITLE
UNDERWATER ULTRASONIC SYSTEM
DIRECT TRANSMISSION
SIZE
CODE
NUMBER
REV
D
UC1204
DATE OCT 10 1988
SHEET 1 OF 1
TOPSIDE DATA ACQUISITION UNIT

Appendix H

ELECTRICAL DESIGN DRAWING FOR ULTRASONIC TEST SYSTEM INDIRECT *MEASUREMENTS*



LCD DISPLAY CONNECTIONS			
LCD PIN	DRIVER PIN	LCD PIN	DRIVER PIN
1	30	21	20
2	NC	22	30
3	NC	23	39
4	NC	24	22
5	11	25	21
6	10	26	26
7	9	27	27
8	30	28	38
9	10	29	15
10	17	30	14
11	16	31	19
12	30	32	20
13	25	33	NC
14	24	34	8
15	23	35	7
16	6	36	12
17	37	37	13
18	33	38	NC
19	32	39	NC
20	29	1 40	30


P1, P2
CABLE CONNECTOR
VIEW OF WIRING SIDE
AS SEEN FROM INSIDE BOX
XMITER SUBASSEMBLY M11
TWISTED SHIELDED PAIR BELDEN 9875 OR EQUIV
ULTRASONIC U-METER PRESSURE HOUSING
LCD DISPLAY
4 LINES X 40 CHARACTERS
DENSITRON PART NO LM44A4C40CBW
LCD DIGITAL DISPLAY -- DENSITRON LSH-6040-FP
FROM ULTRASONIC ASSEMBLY LCD PC BOARD
ULTRASONIC AMPLIFIER
ULTRASONIC U-METER ELECTRONICS
SEE SCHEMATIC DRAWING FOR U-METER
DISPLAY BCD OUTPUT
MA2400 DATA ACQUISITION MODULE
MA2000 POWER SUPPLY MODULE
MA2232 RS232C SERIAL I/O MODULE
MA2000 CMOS MICROCOMPUTER MODULE
PRINTER (HP THINKJET)
PRESSURE
SEPARATION
SIGNAL GROUND
INTERNAL BATTERY BACKUP FOR MEMORY
UNLESS OTHERWISE INDICATED
ALL RESISTORS ARE 1/4 WATT
ALL DIODES ARE 1N5982 OR EQUIV
ALL CAPACITANCES ARE IN uF
ALL RESISTANCES ARE IN OHMS
NAVAL CIVIL ENGINEERING LABORATORY
PORT HUENEME, CA 93043
TITLE
UNDERWATER ULTRASONIC SYSTEM
INDIRECT TRANSMISSION
SIZE D
NUMBER UCI285
DATE OCT 1 1988
SHEET 1 OF 1
TOPSIDE DATA ACQUISITION UNIT

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